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Offshore Waters of the Canadian Pacific Coast¹

By L. A. E. DOE²

Pacific Oceanographic Group

ABSTRACT

Four oceanographic surveys of the Pacific Ocean between the Canadian coast and Longitude 141° W. were undertaken in 1950, 1951 and 1952. The data are analysed to show the temperature, salinity and density structure, and the calculated currents. There is a surface zone about 100 to 150 metres deep in which all seasonal variations occur. This overlies a lower zone of more saline water of constant properties. The currents are weak and sinuous. It appears from these data and comparison with other work that the region lies in the divergence of the Sub-Arctic Current which divides to form the north-flowing Alaska Gyral and the south-flowing California Current. The identity and origins of the water masses are discussed.

INTRODUCTION

PROJECT "Offshore" was commenced in 1950 as an exploratory investigation of the physical oceanographic conditions in the Pacific Ocean off the coast of Canada. The area extended from the continental shelf to Longitude 141° West, and from the latitude of Juan de Fuca Strait (48° 20' North) to the latitude of Dixon Entrance (54° 20' North).

Previous observations in this area appear to have been limited to two crossings by U.S.S. *Oglala* in 1936 and 1939 (Goodman and Thompson, 1940), a few stations occupied by oceanographers of the United States Navy Electronics Laboratory in 1948 (results not yet published), and a study by Tully in H.M.C.S. *Armentières* of a strip 100 miles wide adjacent to Vancouver Island (Tully, 1937). The present studies are the first attempt to cover the larger area systematically or to repeat surveys in successive seasons.

Five surveys were attempted, of which four are discussed in this report. The first in H.M.C.S. *Cedarwood* in August 1950 was completed. The second survey was undertaken in two parts, the first in H.M.C.S. *Cedarwood* in September 1950 and the second in C.G.S. *Wm. J. Stewart* in October. These were frustrated almost completely by storms, consequently the data are of limited value and are not considered here. In 1951 two cruises were completed in H.M.C.S. *Cedarwood*, the first in May and the second in August. In March 1952 a winter cruise in H.M.C.S. *Sault Ste. Marie* covered a little more than half of the area. These cruises are catalogued in Table I.

Although the four cruises were observed in different years it is in some cases convenient to regard the data in the sequence of seasons March (1952), April (1951), and August (1950 and 1951). The duplication of the August data allows the comparison of summer conditions in two years.

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TABLE I. Catalogue of oceanographic cruises contributing to project "Offshore".

Cruise	Number	Dates	Stations	Total stations	Reference surface
					<i>decibars</i>
August 1950	(1-50)	July 28-29, 1950	1-11	89	914
		August 4-11	90-61		
		August 16-25	60-12		
May 1951	(1-51)	May 4-19, 1951	A-1 - G-8	55	900
August 1951	(2-51)	August 1-14, 1951	G-1 - A16	55	900
March 1952	(1-52)	March 6-16, 1952	G-1 - A-20	29	1,000

PROGRAM OF OBSERVATIONS

AUGUST, 1950

The cruise of August 1950 comprised 89 stations taken in the order designated in Table I. Early in the cruise an accident occurred in which several of the reversing bottles were damaged. As a result of this some bottles either leaked slightly or tended to trip prematurely throughout the remainder of the cruise. The data have been examined thoroughly, and all values suspected of error due to either cause have been rejected, but the possibility remains that some of the values used may be inaccurate. It is probable that the principal conclusions are unaffected by any such errors but the detail should be accepted with caution.

The sounding wire was run over a metering block calibrated in yards. Observed values, rather than interpolated values at standard depths, have been used in calculating dynamic heights, which are referred to 914 decibars (914 metres-1,000 yards). Samples were taken at depths of 0, 10, 15, 25, 50, 75, 100, 150, 200, 300, 400, 600, 800, 1,000 and 1,200 yards.

MAY AND AUGUST, 1951

In these cruises four lines were run due west from the coast to Longitude 141° W., with shorter connecting lines between, and stations were numbered consecutively from one along each line in the order in which they were occupied (Fig. 1). In May the area was traversed from south to north, while in August it was traversed in the reverse order.

Stations were occupied at intervals of six hours and were spaced approximately 40 miles apart. The ship was stopped and a serial cast was commenced at 0300, 0900, 1500 and 2100 hours daily. Upon completion of the observations at each station the speed of the ship was adjusted so that the next station would be reached at the specified time. In the event that the exact distance had not been covered at the appointed time, the ship was stopped and a cast made regardless of position, with the result that the distance between stations varied slightly.

This method of spacing observations was adopted so that the effects of internal waves of tidal period might be eliminated by the simplified procedure suggested by Defant (1950). It did not prove feasible to correct for tidal effect

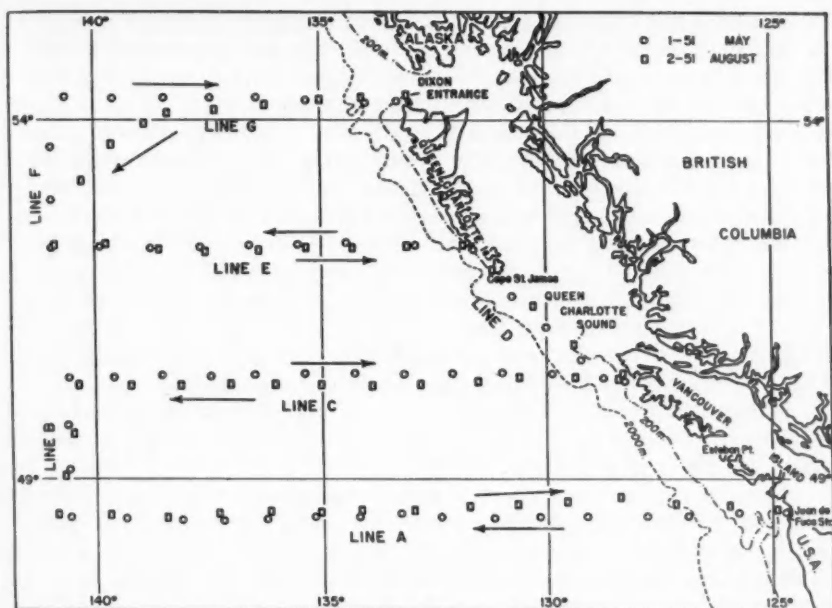


FIGURE 1. Chart of the area investigated off the Pacific Coast of Canada, showing the courses sailed and stations occupied in May and August, 1951. Observations were made along approximately the same lines in the other cruises, although the arrangement and numbering of the stations were different. In the cruise of March 1952 the western limit was about 137° W.

in this manner, but the spacing of stations on a time rather than a distance basis was retained because of its convenience for ship's routine. All values used in the ensuing analysis are as observed, and are not corrected for internal waves.

At the start of both cruises samples and temperatures were taken at depths of 2, 10, 20, 30, 40, 50, 75, 100, 150, 200, 300, 400, 600, 800, 1,000 and 1,200 metres, with a sample also at 125 metres during the August cruise. In both cases the cast had to be reduced in depth during the cruise owing to damage to the sounding wire and the depths of the bottles below 30 metres were altered to 400, 500, 700 and 900 metres.

MARCH, 1952

In this cruise an attempt was made to cover as much of the area as possible in two weeks. Because of winter weather and limited cruising range, only half of the area was surveyed. Since it was expected that the surface layer would be practically uniform to depths of the order of 100 metres owing to winter wind mixing, relatively few samples were taken in this layer, and the extra bottles were concentrated between 80 and 160 metres to obtain more detailed information concerning the gradients in the halocline. The depths used were of 5, 20, 60, 80, 100, 110, 120, 130, 140, 160, 200, 300, 500, 800 and 1,000 metres.

A serious restriction upon the technique of occupying stations was imposed on all cruises except the last by the fact that only one unprotected reversing thermometer was available. This was placed in each case on the bottom bottle, or the one next to it, and served only to indicate whether or not the actual depth reached corresponded to the measured length of wire. If the thermometric depth was appreciably less than the wire depth owing to large wire angle, little significance could be attached to the values obtained, since the curve of the wire was not known. Consequently an attempt was made to ensure that the wire was practically vertical on every cast during the five-minute "soaking time" plus the time required for the descent of the messenger. This is not easy under any but the calmest conditions, and the officers of both H.M.C.S. *Cedarwood* and H.M.C.S. *Sault Ste. Marie* are to be complimented upon their skilful ship-handling, especially in the case of *Cedarwood* which is a single-screw vessel. Casts were successfully completed in winds as high as Beaufort 6.

Bathythermograms were obtained with the ship stopped immediately preceding and following each serial cast and mid-way between serial stations at 0600, 1200, 1800 and 2400 hours.

Seawater samples were stored in 8-ounce medicine bottles, stoppered with pre-waxed corks. The head of the bottle was sealed by immersion in melted paraffin wax. Salinity was measured by the Knudsen procedure in a shore laboratory. Dissolved oxygen content of some, but not all, samples was determined aboard by the Winkler method during the first and last cruises, but was not determined in 1951.

The original data and the detail of the cruises are recorded in Data Records of the Pacific Oceanographic Group (1950, 1951).

ANNUAL VARIATION OF WIND

The seasonal cycle of winds over the Northeastern Pacific is largely determined by the circulation about the North Pacific high-pressure area and the Aleutian low-pressure area (Haurwitz and Austin, 1944; Sverdrup, 1940). In summer the high-pressure area occupies a mean position centred approximately at 40° N., 150° W., which lies to the southwest of the area of this investigation, and results in predominantly west and northwest winds along the southern part of the British Columbia coast. North of Latitude 50° N. these winds tend to be rotated to the left, until off northern British Columbia and southern Alaska the predominant direction ranges from west to southeast.

In winter the high-pressure area move south and east to a mean position at about 30° N., 138° W. At the same time the Aleutian low moves south from the Bering Sea to about 52° N., 180° W., and increases in extent and intensity until it effectively dominates the circulation of the Northeast Pacific. The resulting winds in the British Columbia region are frequently of gale force and range in direction from southeast at the coast to southwest in the offshore region in the vicinity of 140° W. This seasonal variation on the west coast of Vancouver Island is illustrated by the graphs of winds at Esteban Point in Figure 2.

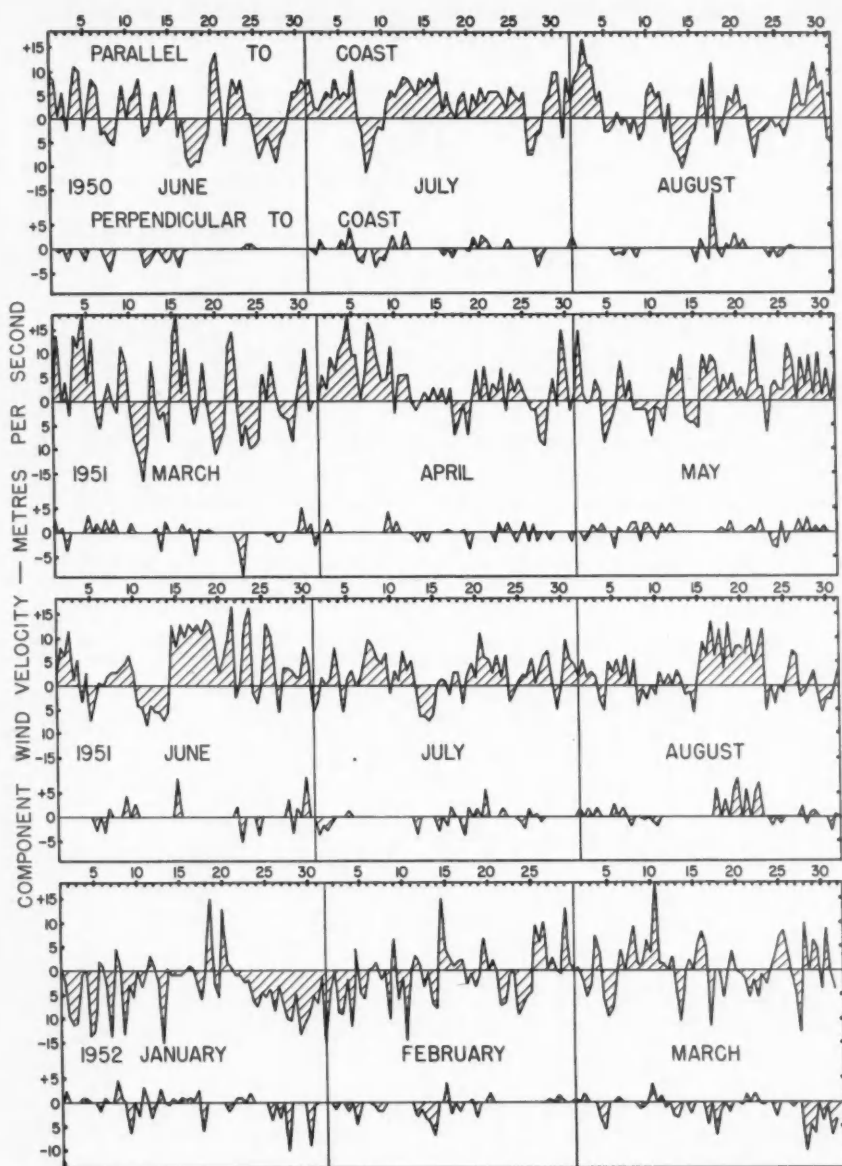


FIGURE 2. Wind vectors parallel and normal to the coast preceding and during the periods of the surveys (Table I). Positive directions are from the northwest and the land, respectively.

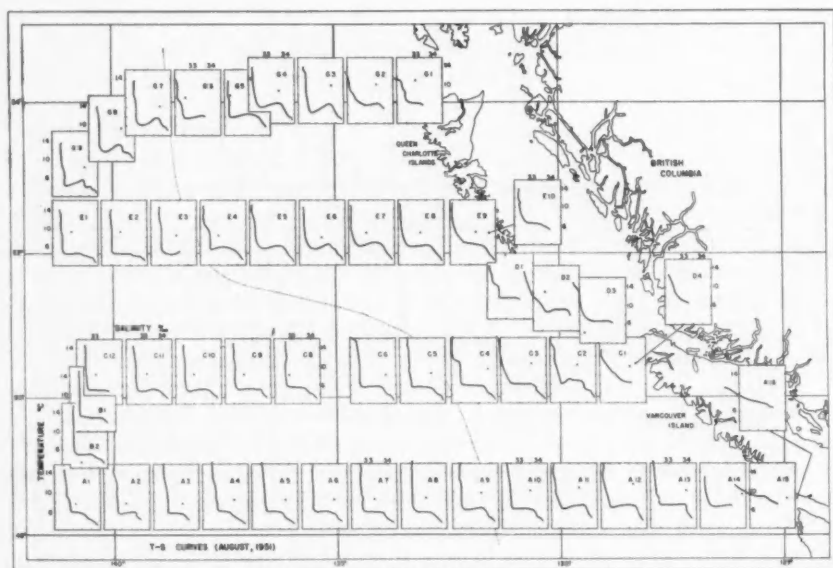
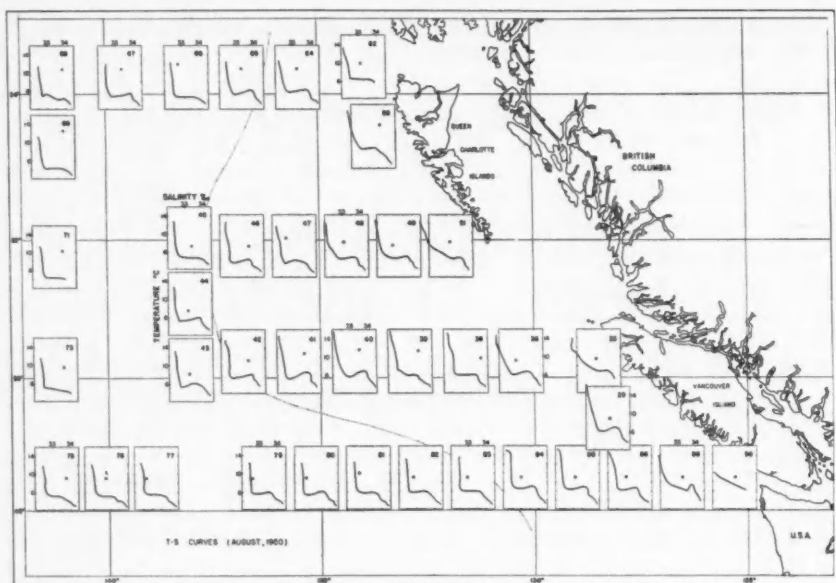


FIGURE 3. Temperature-salinity relations from the data observed off the Pacific Coast of Canada. The dotted line indicates the boundary between the coastal and offshore regions.

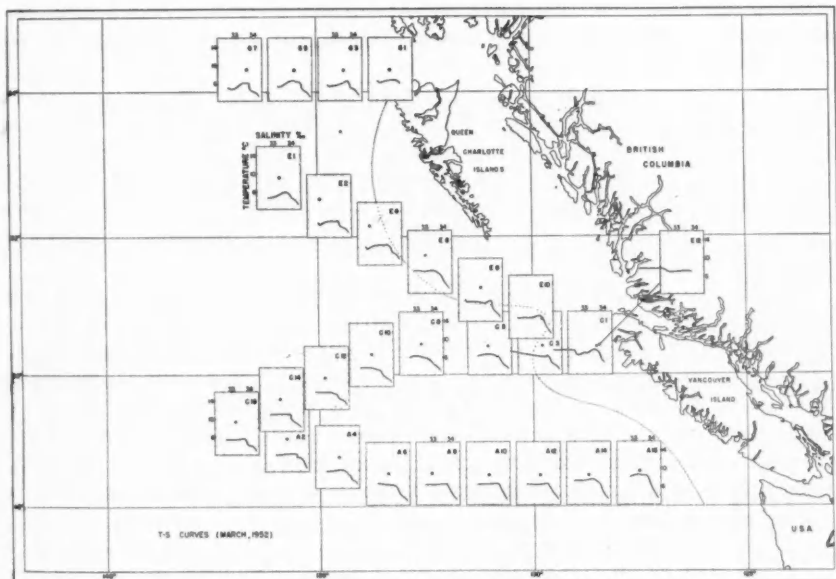
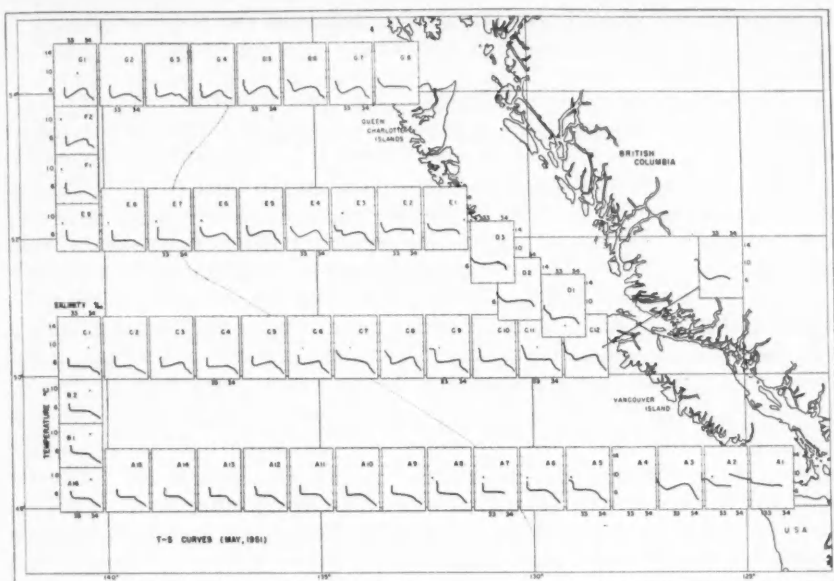


FIGURE 3 (Contd.)

THE STRUCTURE AND PHYSICAL PROPERTIES OF THE WATER

THE THREE ZONES

The most conspicuous characteristic of the water structure of this area is the presence of three distinct layers or zones.³ These may be designated the surface zone, the halocline, and the lower zone. They will be identified by reference to the three segments of a typical T-S curve in Figure 3 from either of the two August cruises or the May cruise. In the top vertical segment salinity is essentially constant while temperature varies. This represents the surface zone, a layer about 100 metres deep. In the horizontal segment temperature is essentially constant while salinity increases with depth. This represents the halocline, a transitional layer of the order of 60 metres thick between the less saline surface zone and the more saline lower zone. The bottom segment corresponds to the lower zone and indicates gradients of both temperature and salinity.

SURFACE ZONE. The properties of the surface zone vary with both season and location. In winter the water approaches vertical homogeneity as a result of cooling at the surface and vigorous wind mixing. In Figure 3 the curves for March 1952 have no top segment, since all data representing the surface zone fall very nearly on the same point. As vernal heating progresses, the surface waters are warmed and a thermocline develops which gradually becomes more pronounced as summer advances. This is illustrated by the elongation of the top segment from March through May to August. With the advent of autumn weather, the surface waters are cooled and mixed to greater depths until the surface zone again becomes vertically uniform. This seasonal variation does not appear to affect the salicline or lower zone.

In the region well offshore the vertical salinity gradients are small at all times but tend to be greater in summer than in winter. These summer gradients are presumably brought about by advection and by the high precipitation in this area, and are preserved under the conditions of strong thermal stability. The excess of precipitation over evaporation is greater in winter than in summer (Jacobs, 1951) but produces less stratification because of the stronger winds and neutral thermal stability.

In the less uniform region near the coast the runoff from the land must be a substantial factor in reducing the salinity of the surface zone. Even in March, when the offshore region was essentially homogeneous to 100 metres' depth, appreciable gradients were observed near Vancouver Island where local drainage reaches a high rate during the heavy rains of winter (Pickard and McLeod, 1953). However, the greatest total runoff occurs in early summer (June) when the large mainland rivers flood as a result of the melting snow in the mountains. Following these floods the fresh water influence is at a maximum and extends farther offshore than in the winter.

³Tully, in his discussion of the oceanography of Alberni Inlet (1949), has used the term "zone" to designate the principal layers in the water structure. This term has the advantage of being more specific in its reference than "layer" which is used variously to designate horizontal strata of any order.

THE HALOCLINE. The transition from the low salinity of the surface zone to the greater salinity of the lower zone occurs in a sharply defined halocline. The range and average of the characteristics of this boundary layer were closely examined in March 1952, and are summarized in Table II. The change of salinity is the most marked, but there is usually a small temperature gradient. In some

TABLE II. Limits of depth, salinity, and density, and the gradient of density, in the halocline, March 1952.

	Top of halocline		Bottom of halocline	
	Range	Average	Range	Average
Depth (metres)	60-150	94	120-200	153
Salinity (S‰)	32.50-32.79	32.62	33.57-33.88	33.75
Density (σ_t)	22.50-25.96	25.71	26.40-26.69	26.57
Gradient of density ($\sigma_t/m.$)				
Range	0.0098-0.0400			
Average	0.0161			

cases this occurs as a slight decrease of temperature with depth; in other cases, especially in the northern part of the area, there is a temperature increase of a degree or more. In all cases, owing to the large gradient of salinity, the halocline is the layer of permanent stability maximum, below the depth of seasonal influence.

LOWER ZONE. Beneath the halocline and extending to the maximum depth sampled is the lower zone, corresponding to the bottom segment of the T-S curve. Following the suggestion of Dr. John P. Tully, observed values of each of S, and T and σ_t were plotted against the logarithm of depth. In each case a remarkably linear relation was observed for the values at depths of 200 metres and greater. The results of a statistical treatment of the data to ascertain the accuracy of such relations have been reported by Tully (1953). In the present case at many of the stations each of the three quantities S, T and σ_t seems to follow a logarithmic gradient to a very close approximation in the lower zone (Fig. 4). The concentration of dissolved oxygen also reveals a linear variation with the logarithm of depth, but with a marked break in the gradient in the vicinity of 500 metres' depth, as shown in Figure 5.

REGIONS

The area investigated can be divided into two principal regions corresponding to variations in shape of the surface-zone segment of the T-S curves. These will be called the "offshore" and the "coastal" regions, respectively. The coastal region probably includes a number of sub-regions according to the local topography, the nature of the land drainage systems, and so forth, which will not be considered in detail here.

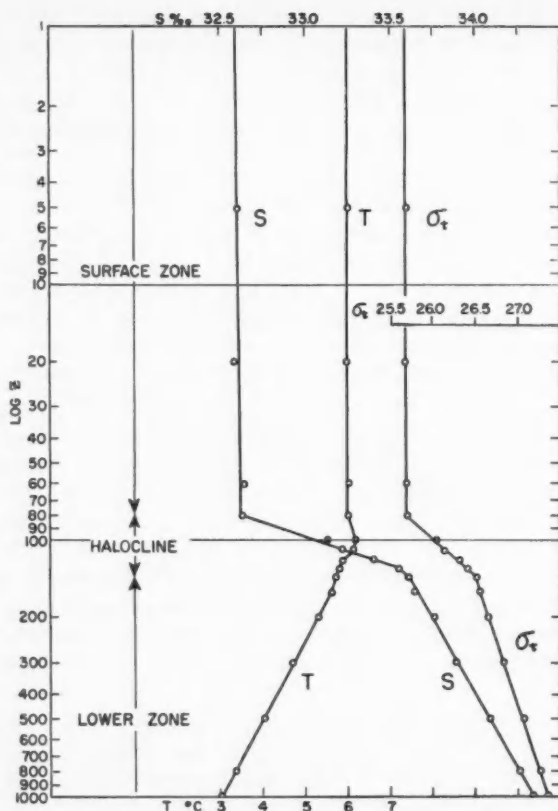


FIGURE 4. Graphs of density (σ_t), salinity (S), and temperature (T), with the logarithm of depth at Station C-8, March 1952. Note the linear relations in each zone.

The division between the two regions is indicated by the dotted lines in Figure 3. West of the line, the surface-zone segments tend to be straight and vertical, indicating a salinity of approximately 32.5‰ with little or no vertical gradient. Toward the coast they are slanted and irregular, representing a salinity less than 32.5‰ at the surface and increasing toward the bottom of the zone. This less saline surface water is apparently the result of dilution by precipitation and by the freshwater runoff from the land. In the approaches to Juan de Fuca Strait there is a tendency for the upper zone and halocline to merge into a single zone with a continuous gradient of salinity.

The lower-zone segments throughout the area tend to be approximately linear with occasional irregularities. They are progressively displaced downward and to the left with distance seaward, as the water of given density becomes colder and less saline. In the western portion, corresponding approximately to

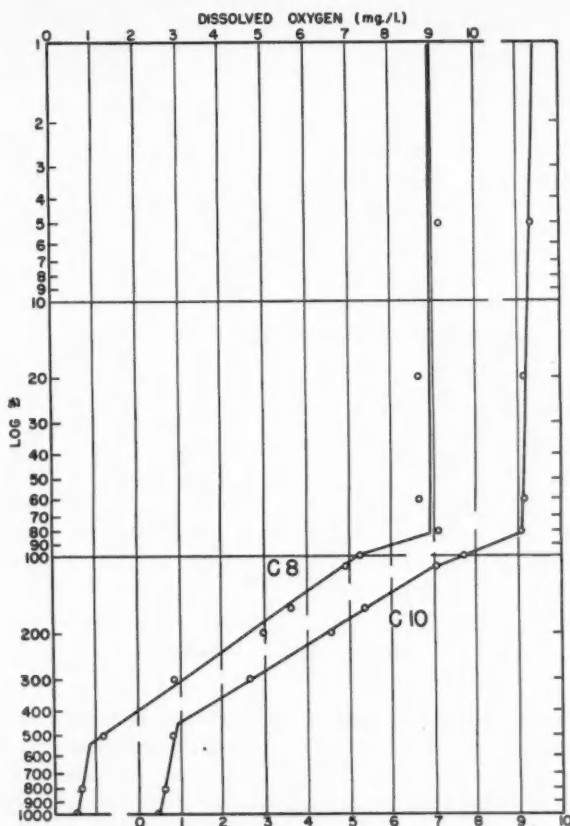


FIGURE 5. Graphs of dissolved oxygen concentration with the logarithm of depth, March 1952.

the offshore region of the surface zone, these segments tend to be regular and form a fairly tight parcel passing through or close to the point $S = 34.0\text{‰}$, $T = 4.00^{\circ}\text{C}$., whereas in the eastern portion the successive displacement is more apparent. The maximum temperature of the zone, that is the temperature indicated at the intersection of the deep zone and halocline segments, similarly decreases progressively to seaward along each line of stations, and the rate of decrease is greater in the eastern portion than in the west.

SURFACE SALINITIES AND TEMPERATURES

As shown in Figure 6 the surface salinity is lowest at the coast, and increases to seaward throughout the area in all seasons. The lowest salinities appear to be associated with Juan de Fuca Strait and Queen Charlotte Sound, and suggest outflows of coastal water. More detailed investigation immediately adjacent to the land would undoubtedly reveal a complex series of systems varying with

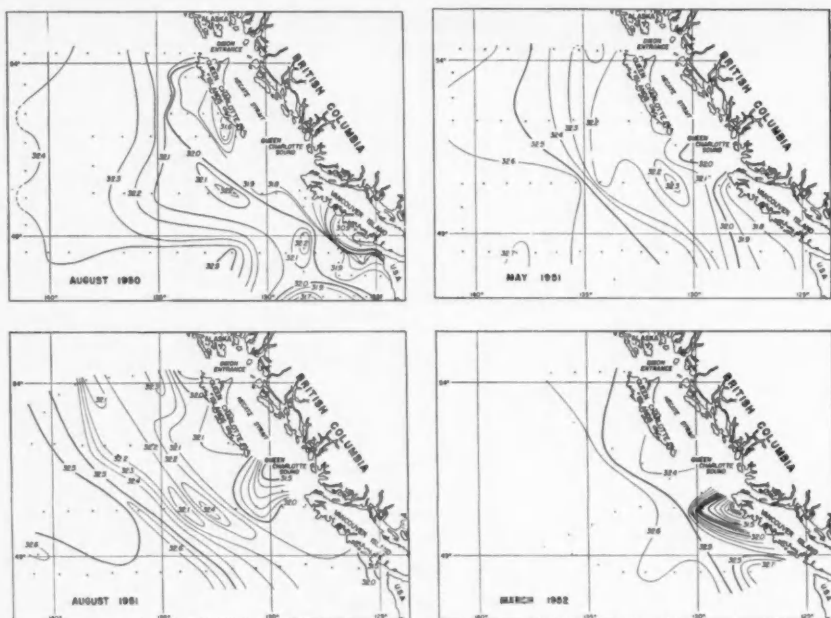


FIGURE 6. Surface isohalines.

the tidal currents as well as with local runoff and discharge from the major drainage systems. In the offshore region the salinity was relatively constant during each survey, but changed significantly from summer to winter. In the summer the fresher waters tend to be conserved near the surface by the stability of the thermocline, hence the salinity is less than in the winter when the waters are mixed to greater depths.

The surface temperatures observed during the four cruises are shown in Figure 7. During the summers the water along the coast is cold, particularly in the approaches to Juan de Fuca Strait. This coastal cold belt appears to be the result of upwelling, which will be discussed below.

In August 1950 several clouds of warm water lay beyond this in a band extending due south from the Queen Charlotte Islands. The warmest water was in the southern part adjacent to the cold water off Juan de Fuca Strait. From the warm band the temperature decreased to the westward to the limit of the survey.

In August 1951 the characteristic strip of cold coastal water was again present, and the temperatures increased to seaward. However, west of this region the isotherms crossed the area essentially normal to the coast. The principal gradient instead of being east-west as in 1950, was practically north-south, and

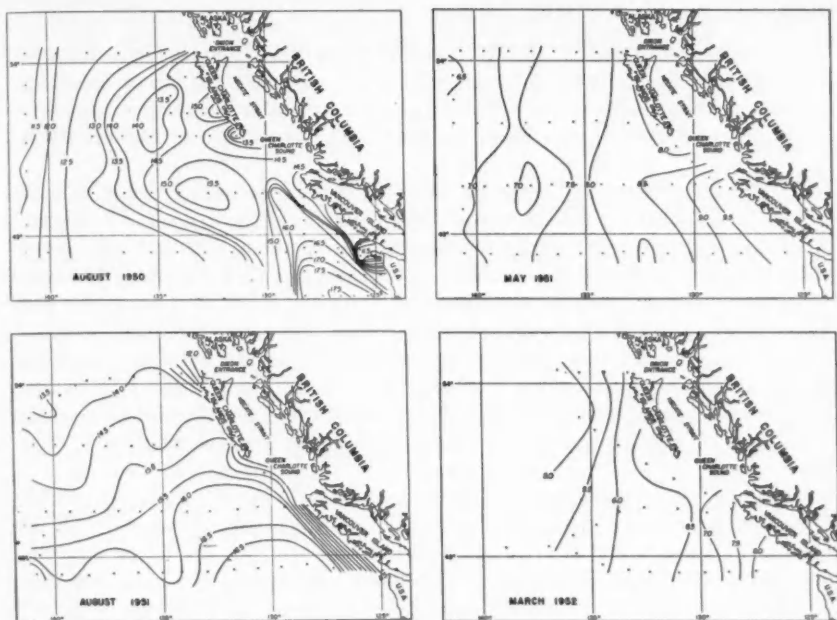


FIGURE 7. Surface isotherms.

while the average temperature was two degrees higher in 1951, the range was smaller. This picture represents a distinctly different type of situation from that observed in the previous summer.

It is interesting to note in passing that during August 1950 vast numbers of *Veleva* were observed throughout the entire areas of this investigation west of about Longitude 130° W. Large numbers were visible at all times, and they frequently occurred in such concentration as to look like great streaks of foam on the water. By the crudest of calculations it was estimated that the number in the area contained by the outer lines of stations and the coast would be of the order of 10^{10} to 10^{12} , and it is not known how much farther they extended in all directions. In August 1951, on the other hand, when the water was warmer, not a single specimen was observed throughout the cruise.

In the winter the warmest water is along the shore, becoming colder to seaward. In March 1952 the surface isotherms ran essentially north and south, with the warm water on the east. In May 1951 the whole area was some two degrees warmer, but the contours were similarly arranged. It appears likely, therefore, that the distribution of surface temperatures throughout the early months of 1952 was similar to that in the same period of 1951 and probably is typical of winter and spring conditions.

VERTICAL SECTIONS

Vertical sections of temperature, salinity and density (σ_t) from the shore seaward along the principal lines (Fig. 1) of the August 1951 survey are shown in Figures 8 and 9. In order to show the seasonal variation the corresponding sections along Line A from each of the four cruises are shown in Figures 10 and 11.

The thermocline is indicated by the concentration of isotherms between the surface and approximately 70 metres' depth. Similarly the halocline is marked by the concentration of isohalines between approximately 100 and 160 metres, with excursions beyond these limits in some places. In all the sections of Figure 8 the thermocline is very nearly horizontal from the seaward limit to the continental shelf. From there it slopes upward toward the coast, forming the coastal temperature gradient as successive isotherms intersect the surface. Below the thermocline the isotherms slope downward toward the coast, with an inclination that increases with depth, at least to the 4° isotherm. Thus the warmest waters at any level in the lower zone are found nearest the coast at all seasons (Fig. 10).

An apparent exception to this is found on Line G in Figure 8 where a marked depression at Station 5 tends to obscure the general trend. Common to all the lines are apparent "cells" or pockets of warm water which occur in the halocline zone just west of the continental shelf. These correspond to the temperature inversions which were mentioned in the discussion of the T-S curves of this locality, and indicate where the water at the top of the lower zone is warmer than the water at the bottom of the surface zone.

The division between offshore and coastal regions is indicated approximately by the intersection with the sea surface of the $S = 32.50\text{‰}$ isopleth on Lines A and C, and of the $S = 32.25\text{‰}$ isopleth on Lines E and G. East of this point in each case the isohalines of the surface zone form an open U-shape, as though the low-salinity water lay in a trough extending parallel to the coast and varying from 300 to 500 kilometres wide.

Immediately beneath the upward-sloping isohalines on the landward side of this trough the halocline rises toward the coast. This is especially noticeable on Line A (Fig. 8), where the isopleths of $S = 32.75\text{‰}$, for instance, rises from 130 metres at Station 9 to 25 metres at Station 15, and 33.50‰ from 185 metres at Station 9 to 50 metres at Station 15. On each of the other lines an abrupt upward inclination occurs at the landward end. On Lines C and E this represents a rise of some 40 to 80 metres between the two most easterly stations. On Line G the depression at Station 5 results in a rise of the isohalines by some 80 metres between Stations 5 and 1.

The inclination of the isopycnals in the halocline zone is similar to that of the isohalines. Beneath the halocline, the isopycnals slope downward to the east with the isotherms, suggesting the mass distribution of a gradient current toward the north.

In Figures 10 and 11 the vertical sections along Line A of the two summer cruises are essentially similar except for the difference in surface temperatures.

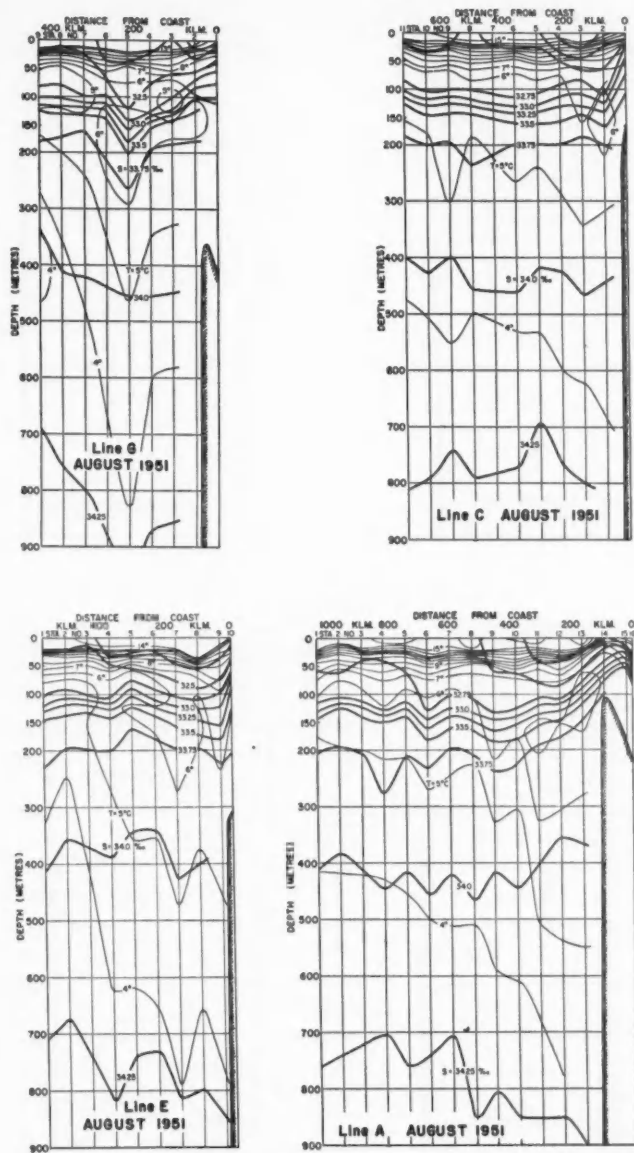


FIGURE 8. Vertical sections showing the distribution of temperature ($^{\circ}\text{C}$., light lines) and salinity ($S\text{‰}$, heavy lines) as observed in August 1951. The location of the lines is shown in Figure 1.

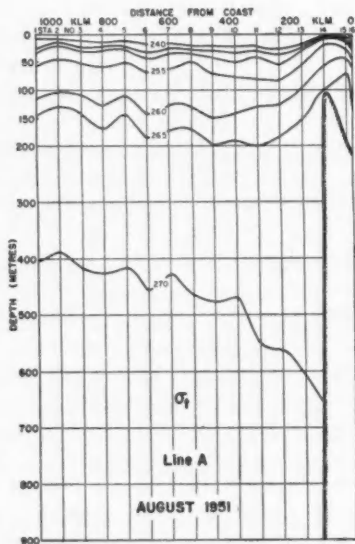
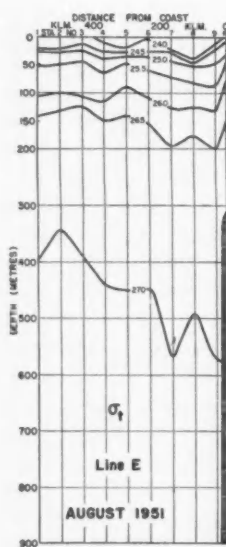
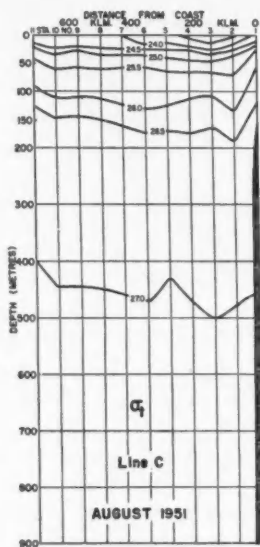
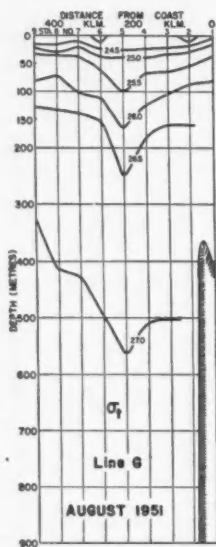


FIGURE 9. Vertical sections showing the distribution of density (σ_t) as observed in August 1951. The location of the lines is shown in Figure 1.

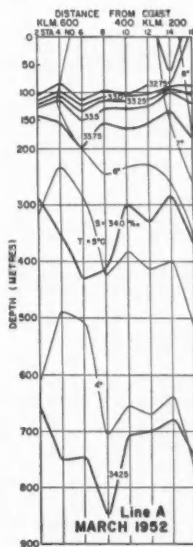
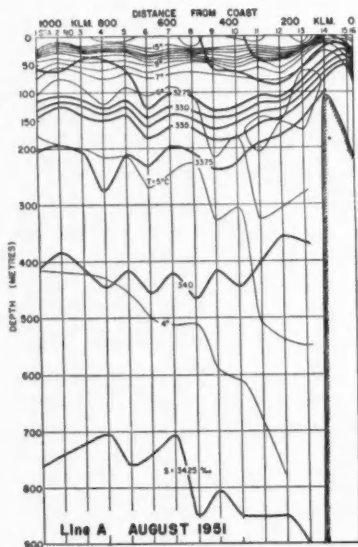
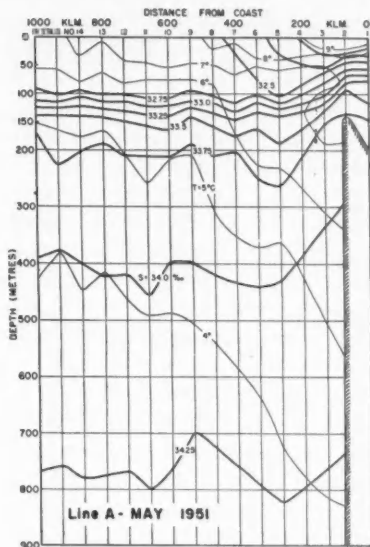
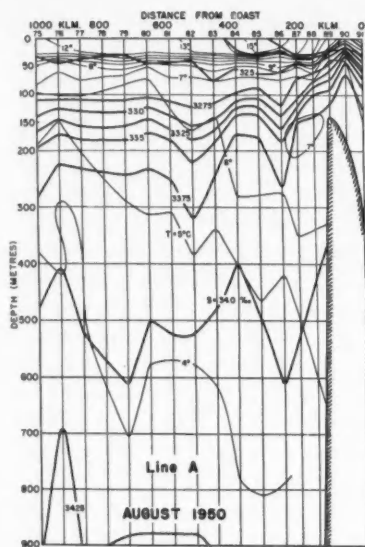


FIGURE 10. Vertical sections showing the distribution of temperature ($^{\circ}\text{C}$, light lines) and salinity (S ‰, heavy lines) as observed on Line A during each of the four cruises. The location of Line A is shown in Figure 1.

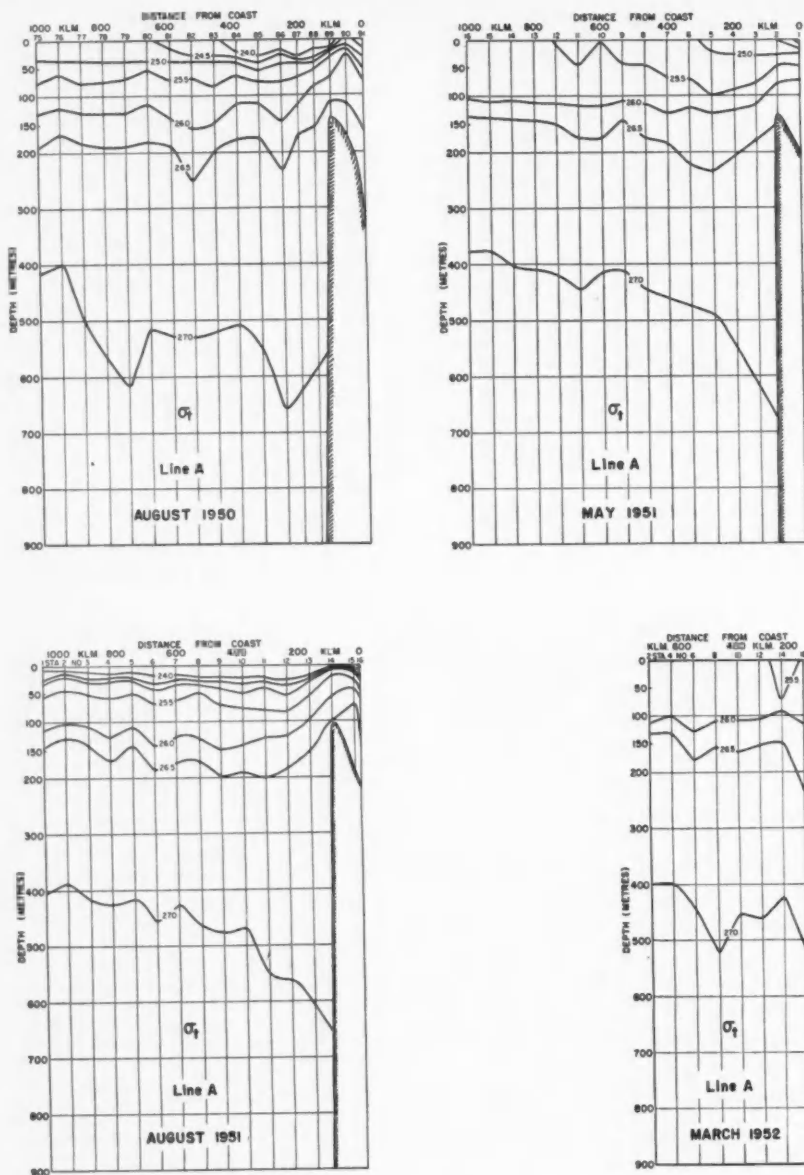


FIGURE 11. Vertical sections showing the distribution of density (σ_t) as observed on Line A during each of the four cruises. The location of Line A is shown in Figure 1.

Proceeding west in August 1950, successive isotherms curve upward from the thermocline to intersect the sea surface, whereas in August 1951 only minor fluctuations of surface temperature occur (see also Figure 7). The other sections of the August 1950 cruise, which are not shown here, reveal the same feature. They also show less upward inclination at the coastal end than do the corresponding sections in Figure 8, and on Line G all the isopleths slope downward toward the coast.

In spring (May 1951) the distribution of temperature and salinity is similar to that found in August, except that the surface water is colder and the thermocline is not as well developed. In each section the band of low-salinity water in the coastal region occupies essentially the same position, and the temperature inversions are similar. The upward inclination of the shoreward end of the halocline is present but less pronounced.

The sections from the March 1952 cruise are distinguished by the absence of vertical gradients in the surface zone, except in the coastal region. In the northern sections (not shown here, but see the first frame of Figure 14) the isopleths of the surface and halocline zones are horizontal in the offshore region as during the other cruises, but in the coastal region slope downward toward the coast. It is not certain if this phenomenon occurred on Line A since the observation of the shoreward end was precluded by a storm. However the surface-zone isotherms at Stations A14 and A16 and the isopleths of $\sigma_t = 26.0$ and 26.5 indicate a downward tendency, and it seems likely that this continues toward the coast.

DISCUSSION

At any position there are effectively two water masses comprising the surface and the lower zone, respectively, and separated by a marked transitional layer, the halocline. Treating this as a boundary zone, if the horizontal trajectories of the surface and lower-zone waters were identical, the properties of the halocline at each place could be considered as derived from the water immediately above and below it. Differences between the isentropic charts of successive density (σ_t) surfaces indicate that the movements are not precisely in the same directions at all depths, and hence the water at different levels in a particular column within the halocline will probably be derived from various surface and lower-zone combinations. On the other hand, the two water masses involved each have sufficient lateral homogeneity that the boundary layer in most cases has to a good approximation the properties of a mixture of the waters above and below it.

The effectiveness of the halocline as a barrier to the passage of water from the lower to the surface zone or vice versa is indicated by the range of densities and density gradients found on it. Table II shows values obtained from the data of the cruise of March 1952, in which the most detailed sampling was made of the halocline. The minimum value of σ_t at the bottom of the zone is 0.44 greater than the maximum at the top. There must, therefore, be very little transfer of water between the surface and lower zones.

Because the halocline is below the level of seasonal influence, and because there is an inferred absence of vertical exchange between the surface and lower zones, the temperatures observed immediately above and below the boundary layer can be considered as properties of the respective water masses. The upper zone is vertically homogeneous in winter and attains its annual minimum temperature at this time. If it is assumed that maximum wind-mixing ceases before vernal heating has progressed appreciably, it follows that the temperature observed in summer beneath the thermocline, that is, the temperature immediately above the halocline, should be approximately the temperature that this water had when it was part of a homogeneous layer the previous winter. The temperature at the bottom of the surface zone may therefore be considered to be a quasi-conservative property of the surface water mass. Similarly the temperature at the top of the lower zone may be considered a conservative property of the lower water mass.

The temperature of the surface isothermal layer at any time is in general the result of both the average temperature of the water prior to mixing and the climate in which mixing occurs. It may be assumed that if the water remains in a region where there is a sufficiently prolonged winter of constant climatic conditions, the water temperature will eventually reach an equilibrium value which will be a function of climate only and independent of initial conditions. If, on the other hand, the wind attains sufficient vigour early in the season to stir the water before the thermocline has been completely destroyed by cooling from above, or if the water is being transported from a warmer to a colder region, the resulting temperature will be higher than the equilibrium value. If the temperatures observed in the surface zone in March are equilibrium temperatures, it implies that the effective winter climate is the same along any given isotherm. Since these isotherms run principally north and south, such a constancy of effective climate would be surprising, and it follows that the water advected along the coast must be warmer than that farther to seaward.

This would be the case if the eastward flowing Sub-Arctic Current, or part of it, turned to flow northward through this area.

CURRENTS

DYNAMIC TOPOGRAPHY AND GRADIENT CURRENTS

Charts presented in Figure 12 show the calculated dynamic topographies of the sea surface and the implied gradient currents for the four cruises.

The contours of dynamic-height anomaly in August 1950 indicate that the circulation is dominated by eddies except in the northwest corner where the flow is toward the northeast. In the southeast corner there appears to be part of a large anticyclonic eddy extending southward out of the area. This is associated with a southerly flow off the coast of Vancouver Island and the State of Washington. It appears that the currents divide, those in the north moving northward and those in the south moving southward, with a region of eddies between them.

In May 1951 the flow is northward but weak and sinuous with very small velocities except in the northwest corner. A similar situation exists in August 1951 where the velocity is no greater than in the spring.

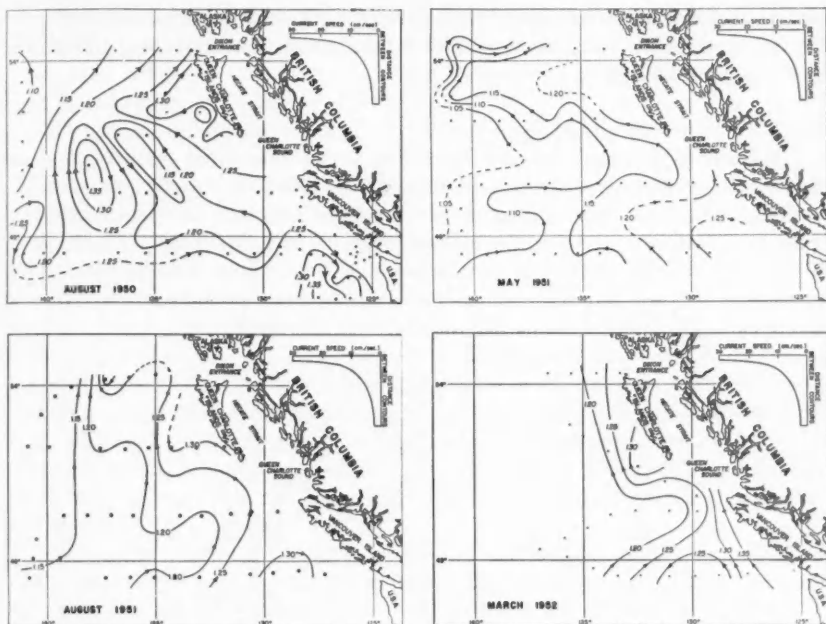


FIGURE 12. Calculated geopotential topography of the sea surface (anomaly of dynamic height in dynamic metres) and implied gradient currents. Arrows indicate the direction of flow. The inset diagram shows the current speed in relation to the distance between isobars. The reference surface is 914 decibars for August 1950, 900 decibars for May and August, 1951, and 1,000 decibars for March 1952.

In March 1952 the indicated velocity is appreciably greater and the pattern of northward flow is more definitely established than in the other months. Only about two-thirds of the area was covered by the cruise, but in this portion all the stream-lines enter from the south. It seems likely that the northward flow through the area is stronger in winter than in summer.

In general the currents are weak and variable. The principal direction of flow indicated by all of the charts is from south to north, with some of the stream-lines also entering from the west and curving to the north. The speed in all cases is small, with average values of the order of 5 centimetres per second ($2\frac{1}{2}$ miles per day) or less and maxima up to 20 centimetres per second (10 miles per day) in spring and summer. In March the speed is of the order of 10 centimetres per second in the coastal region but is apparently less farther to seaward.

Dynamic topographies of the 100-, 200- and 300-decibar surfaces for each cruise have also been studied. In general, the indicated currents in each case are similar to those at the sea surface, but the speed decreases with depth until at 300 metres it is approximately one-half that at the surface. An exception to this is found in March 1952 when the surface velocity is twice that observed in the other cruises, but the velocity at 300 metres is substantially the same. Some such

increase in surface-current speed to the north is to be expected in winter under the influence of the cyclonic wind circulation which is predominantly from the southwest in this region.

ISENTROPIC ANALYSIS

In view of the weakness and variability of the calculated gradient currents the method of isentropic analysis (Montgomery, 1938) was studied as a supplementary means of determining the circulation pattern. The distribution of temperature was examined on the surfaces of $\sigma_t = 25.00, 25.75, 26.00, 26.50, 26.75, 27.00, 27.75$, or such of these as were applicable, for each cruise. The distribution of dissolved oxygen has been similarly treated for some portions of the first and last cruises. Two typical charts are illustrated in Figure 13.

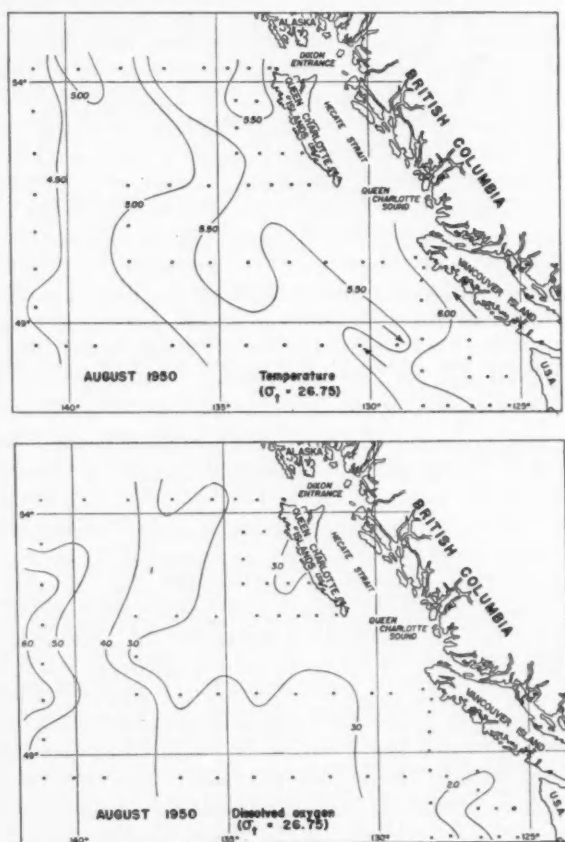


FIGURE 13. Charts showing the distribution of temperature ($^{\circ}\text{C}.$) and dissolved oxygen concentration (mg./l.) on the surface of $\sigma_t = 26.75$ in August 1950.

It is assumed that the flow is in general parallel to the isotherms except where sharp changes in directions occur. In such cases, notably where the contours form a "tongue", it is assumed that the net flow is along the tongue with maximum mixing occurring at the tip.

In general, the principal direction of flow suggested by the isentropic charts is similar to that indicated by the calculated dynamic topography. Considerable difference in detail is evident, but since the purpose of this paper is to consider general tendencies, minor differences have been ignored. The assumption that the calculated gradients are a reasonable indication of principal movements is apparently justified.

In the charts of all the surfaces examined, the direction of the isotherms is predominantly either north and south or parallel to the coast. In the upper zone some of the lines tend to enter the area from the west and leave to the north, whereas near the coast the tendency is to pass from south to north. Thus the isotherms converge toward the north, in agreement with the convergence of the contours of dynamic height and the implied acceleration of the gradient currents. The proportion of isotherms entering from the west tends to decrease with depth until, at the $\sigma_t = 27.0$ surface, all of the principal lines are approximately parallel to the coast.

These observations, combined with the calculations of gradient flow, indicate that the direction of flow is principally northwestward along the coast at all depths examined, with some convergence of streams from the west, especially in the upper layers.

UPWELLING

Upwelling has been advanced as an explanation of the cold saline water found at the surface along the west coast of Vancouver Island in summer (Tully, 1938; Pickard and McLeod, 1953) and of the high concentration of phosphates near the mouth of Juan de Fuca Strait (Igelsrud *et al.*, 1936). Tully's observations and conclusions anticipate in large part those which are presented here. It appears that when the surface waters are moved offshore by winds from the northwest, they are replaced in part by the upwelling of deeper waters along the coast.

It has been shown in Figure 2 that northwest winds are most prevalent in the summer, and in Figure 8 that the thermocline and halocline approach the surface along the coast in the summer. The seasonal comparison in Figure 10 is not entirely satisfactory, since the coastal segment of Line A was not completed in March 1952. It is convenient to compare the cross-sections of density (σ_t) on Line C from the four cruises as shown in Figure 14. If it is assumed that each of these sections is representative of its particular season and associated conditions, the variation in slope at the coastal end is striking. The isopycnal of $\sigma_t = 26.5$, for instance, rises from 180 metres in March to 150 metres in May and 120 metres in August 1951, or 145 metres in August 1950.

The March 1952 cruise followed a period of fairly strong variable winds which were predominantly southeast, especially prior to the middle of February.

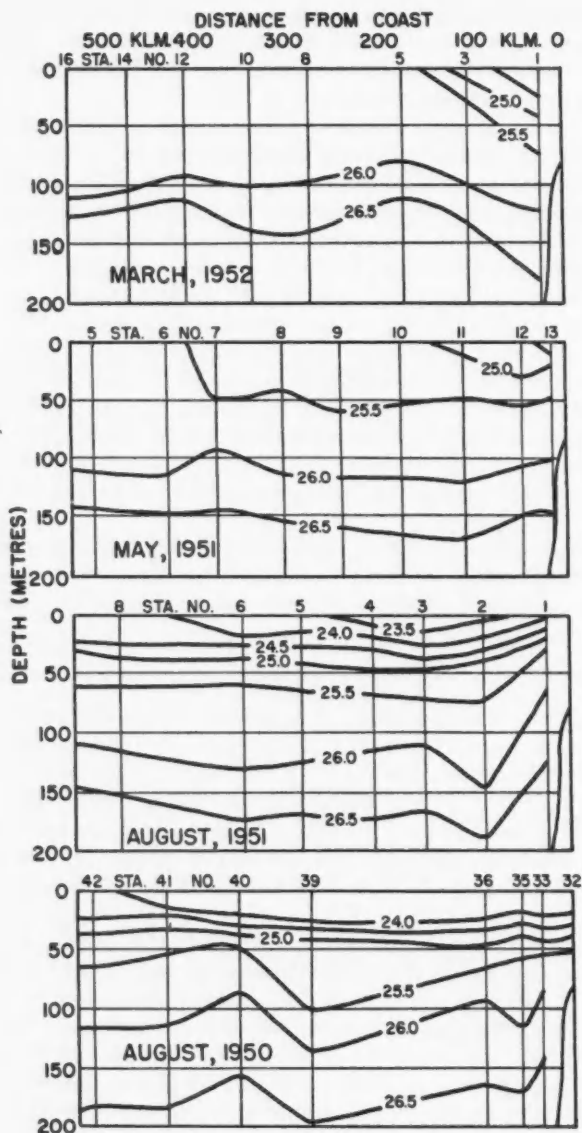


FIGURE 14. Vertical sections along Line C seaward from the north end of Vancouver Island (Fig. 1), showing the distribution of density (σ_t) from the surface to 200 metres' depth.

The other three cruises were preceded by predominantly northwest winds, the most prolonged and consistent period being that before the August 1951 cruise, which showed the most marked upwelling.

If the properties of the water do not change as it rises, the σ_t surfaces would be expected to intersect the sea surfaces when upwelling occurs. In the present case the upwelled water will be heated as it rises in summer and its density will be reduced, so that the vertical motion will have a component across the σ_t surfaces. In Figure 8, for example, the isohalines in August 1951 are inclined upward more steeply than the isotherms, as would be expected if the more saline water from below was warmed as it upwelled. In this respect the increase of salinity due to upwelling apparently more than offsets the dilution at the coast by land drainage. The combined effects of dilution and warming reduce the inclination of the σ_t surfaces in the upper layers compared with those somewhat deeper.

Igelsrud *et al.* (1936) have deduced from the distribution of phosphates that water upwells from below 500 metres' depth to between 100 and 265 metres' depth. The evidence from the present data, however, indicates that all the upwelling occurs from depths less than 200–300 metres, since below this the isopleths slope downward toward the coast. This is similar to Sverdrup's conclusion (1938) that off the coast of California the upwelled water comes from depths not exceeding 200 metres.

The situation in which upwelling occurs along the British Columbia coast differs from that on the California coast since the prevailing gradient currents in the two cases flow in opposite directions (or at least did in the summers of 1950 and 1951). Northwest winds in California tend to accelerate the current and impart an offshore component which results in upwelling. The eddy indicated near the mouth of Juan de Fuca Strait by the dynamic topographies in Figure 12 represents a southward current off the coast which could react to northwest winds in this way. This may explain the greater evidence of upwelling on Line A than on the other lines. Elsewhere along the British Columbia coast a northwest wind opposes the prevailing current, but apparently can result in a southeastward flow immediately adjacent to the coast. Farther to seaward the flow is southeast relative to a shallow surface such as 100 or 200 decibars, while relative to a deeper surface, such as 900 decibars, it continues to move north or northwest. This is illustrated by the dynamic-height anomalies of the sea surface along Line C depicted in Figure 15. Station C-1 is located over the continental shelf where the sounding is 163 metres. Relative to 100 decibars a strong southerly component in the gradient current is indicated between C-1 and C-2. Between C-2 and C-3 the current relative to 100 decibars is weaker but still southward, whereas relative to 900 decibars it is northward. West of Station C-3 the flow is northward relative to both surfaces, with the exception of the meander around Station C-5 (Fig. 12). These differences are small but appear to indicate that near the coast the northwest wind retards the flow to the northwest at the surface as compared with that beneath the surface, and, in the shallow water of the shelf at least, results in a southeasterly flow immediately adjacent to

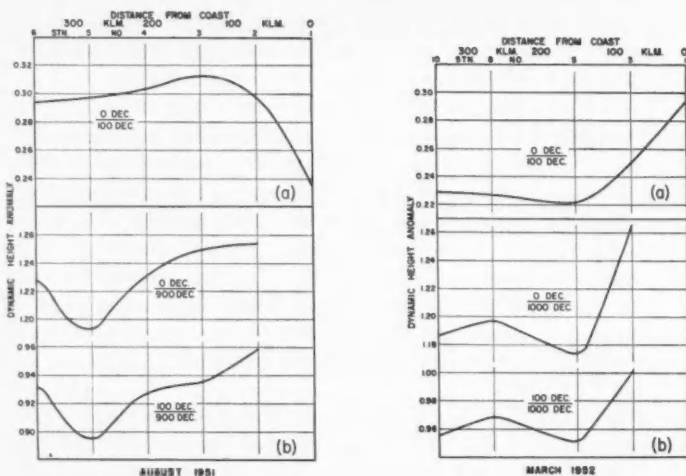


FIGURE 15. The dynamic height anomaly along Line C in August 1951 and March 1952, (a) of the sea surface relative to 100 decibars, (b) of the sea surface, and of the 100-decibar surface, each relative to 900 decibars in August 1951, and relative to 1,000 decibars in March 1952.

the land. In March 1952, on the other hand, under the influence of southeast winds strong flow to the northwest is indicated relative to all surfaces.

Sverdrup has shown that upwelling off the coast of California is associated with the accumulation of light surface water offshore and the development of a narrow stream flowing parallel to the coast and some distance from it. A similar but less pronounced occurrence of this phenomenon is suggested by the isopleths of σ_t in the third frame of Figure 14 (August 1951), where the lightest surface waters are observed at Stations 2, 3 and 4. In winter this water is confined in a narrow region close to the coast, since southeast winds impart an onshore component of motion. In summer northwest winds tend to move it offshore with the resulting upwelling and establishment of southeasterly gradient currents, which in this case are adjacent to the coast.

ORIGINS AND CIRCULATION OF THE WATER

It is expedient to compare the observations of these surveys with other recorded data from the same and adjacent areas. The positions of the stations considered are shown in Figure 16.

SURFACE ZONE

The water which moves northward along the coast of British Columbia and Alaska and that which moves southward along the coast of the United States, must approach North America from the west. This is in accordance with the statement of Sverdrup *et al.* (1942) who attribute this water to the Sub-Arctic or Aleutian Current. The stations occupied by U.S.S. *Bushnell* in 1934 (*ibid.*)

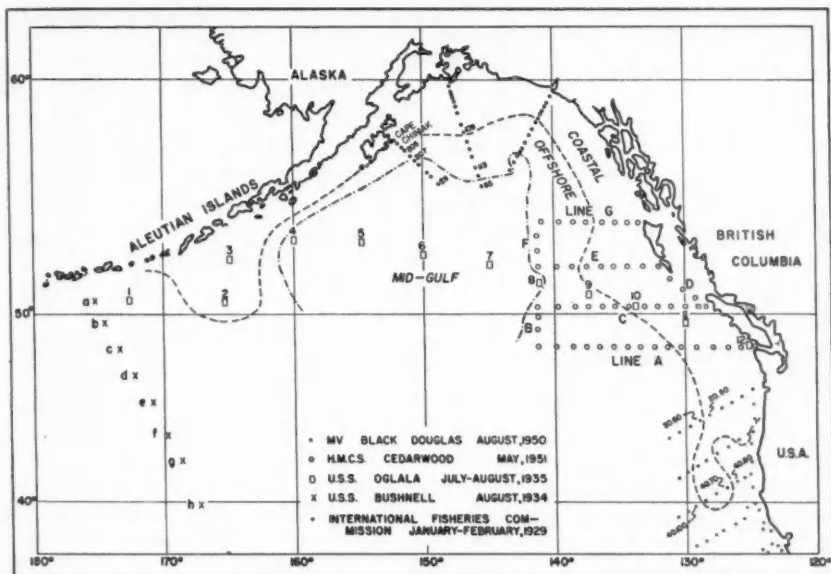


FIGURE 16. Positions occupied by several expeditions in the Northeast Pacific Ocean. The contours indicate the inferred division of the water masses in the surface zone. T-S curves of the *Cedarwood* stations are shown in Figure 3; those of the other stations are shown in Figure 17.

crossed this current and indicate the properties of the water advancing eastward at approximately Longitude 170–175° W. The T-S curves of these stations are given in Figure 17.

It was only in the upper 35 metres of Stations (a) and (b) near the Aleutian Islands that the *Bushnell* observed salinities as low as those found in the offshore region. Thus it seems impossible to attribute the great quantity of low-salinity surface-zone water in the British Columbia area and the Gulf of Alaska to transport eastward across the *Bushnell* line. Dilution must occur farther west.

In 1935 U.S.S. *Oglala* occupied a series of stations from Dutch Harbor, Alaska, to Juan de Fuca Strait (Goodman and Thompson, 1940). By means of T-S curves, reproduced in Figure 17, they identified an area of "southern Aleutian water" which is here called "mid-gulfwater", lying immediately westward of the offshore region.

Oglala Stations 2 and 3 near the Aleutians show upper-zone salinities that agree well with those observed in the western portion of our coastal region. Stations 4–8 form the southern-Aleutian or mid-gulf region, with salinities only slightly higher than those of our offshore region. Station 1 shows the influence of Aleutian water similar to that of *Bushnell* (2). The transport across the *Oglala* line of stations was southward between Stations 1 and 4, indicating a con-

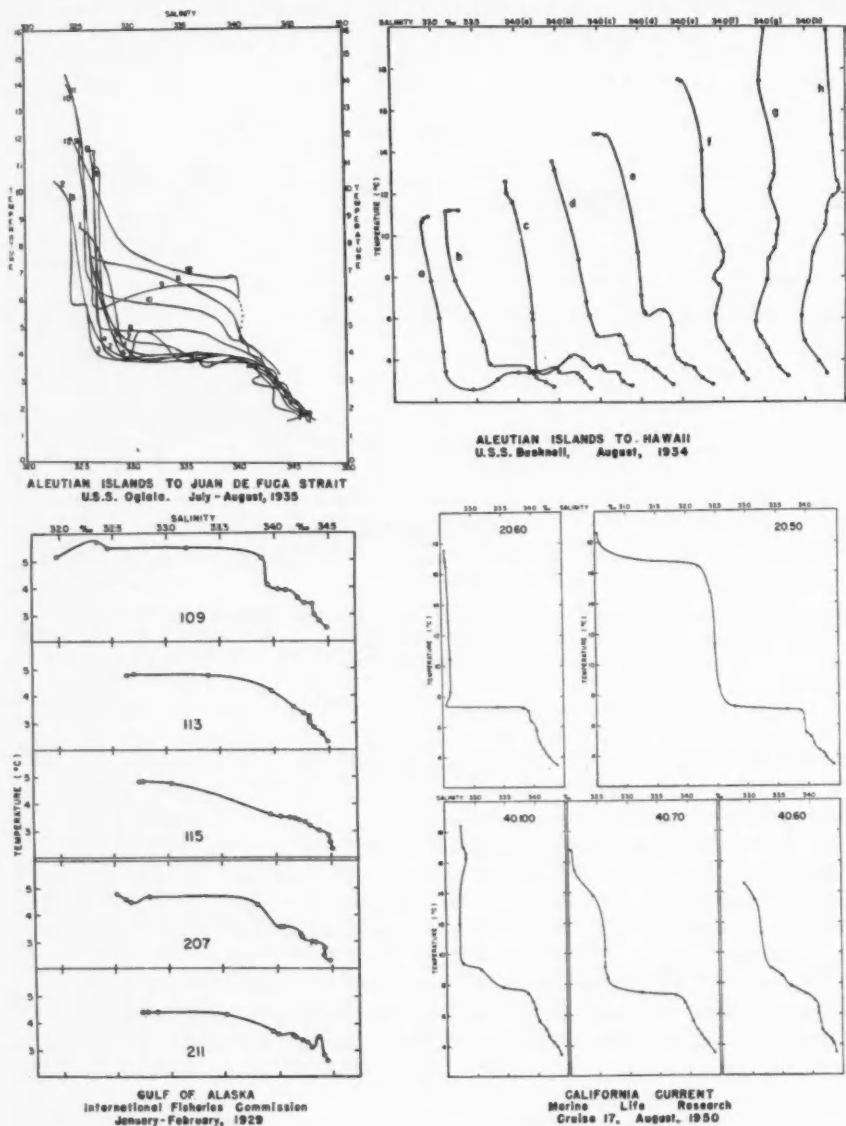


FIGURE 17. Temperature-salinity relations observed in the Northeast Pacific Ocean. The positions of these stations are shown in Figure 16.

vergence of the waters moving out of the Gulf of Alaska with those moving eastward in the Sub-Arctic Current. The mixture of these components, further diluted by heavy rains, could result in a salinity such as is observed in the offshore region off British Columbia.

There is a suggestion in the data from the 1950 and 1951 cruises, which attained Longitude 141° West, that the western edge of the area borders on the mid-gulf region. At some of the stations along this limit the temperature at the top of the deep zone (Fig. 3) is of the order of a degree colder than at the adjacent stations. This results in a marked flattening of the central (halocline) segment of the T-S curves. The surface-zone water in each case is similar to that in the offshore region.

In both 1951 surveys surface-zone water of salinity slightly higher than elsewhere was observed in the southwest corner of the area. Such water exists both to the west in the mid-gulf region, and also to the south of our area. On the basis of salinity alone it is not possible to distinguish between these two origins, but the minimum temperature of the surface zone suggests that it was mid-gulf surface-zone water again intruding into the offshore region, and over-riding the water of the lower zone. A similar case occurred in 1936 at *Oglala* Station 8.

Low-salinity upper-zone water corresponding to our coastal region has been observed off the coast of the United States as far south as Latitude 40° , where it extended as a tongue separated from the coast by more saline water (Fig. 16). The low salinity of this water must be due to heavy precipitation and to runoff from the land, both of which are highest in the region extending from Oregon northward through Washington, British Columbia and Alaska. Its extension southward would be explained by the southerly flowing California Current. In British Columbia waters its movement is predominantly northward but is characterized by frequent sinuities and back-eddies.

Observations made by the International Fisheries Commission in 1928 (McEwen *et al.*, 1930) (Fig. 16, 17) indicate that a corresponding division existed between coastal and offshore regions at the head of the Gulf of Alaska on three sections. From the 1929 observations of Thompson *et al.* (1936), a division is again apparent on all three sections, but the salinity in the coastal portion of the Cape Chiniak section was higher than on the other two. Similarly its temperature (winter) was more uniform. This difference between the Chiniak section and the other two, the authors suggest, may have been "due to the lack of any large freshwater outlets near the section as well as to the great mixing of the waters by currents produced by winds and tides over the shallow banks". The net movement across all these sections was to the west.

Thus this low-salinity water in the upper zone appears to be continuous in the coastal region around the entire shoreline from Oregon into the Gulf of Alaska, and circulating around the gulf in a counterclockwise direction.

At the western extremity, in the vicinity of the Aleutian Islands, the stream divides. Part moves through the channels into the Bering Sea (Thompson and Van Cleve, 1936) while the remainder continues to move southward until it joins the eastward-bound Sub-Arctic Current. This circulation is schematically

represented in Figure 18. The low-salinity surface-zone water found throughout the Gulf of Alaska is probably due to the conservation and re-circulation of a substantial portion of the coastal water, as well as to the high precipitation associated with the semi-permanent Aleutian low-pressure area.

Thompson and Van Cleve (1936) have deduced from drift-bottle experiments that in March 1932 the division of the Japanese Current (which is here called the Sub-Arctic Current following Sverdrup *et al.*, 1942) to form the Alaska and California Currents occurred well south of Latitude 47° N. They point out that this conforms to the latitude of the division between residual winds with a northerly component and those with a southerly component as calculated from the Pilot Charts of the U.S. Hydrographic Office. The resulting current along the coast of British Columbia agrees well with that calculated from the March 1952 cruise (Fig. 12).

Thompson and Van Cleve also conclude from drift-bottle experiments conducted in July and August, 1931, that the division of currents in August occurred at Latitude 50° N., which again agrees with the division of winds deduced from the Pilot Charts. These bottles were released along a line approximately parallel to the west coast of Vancouver Island and the Queen Charlotte Islands and 100 miles to seaward of them. Tully (1937) calculated that outside a coastal region of the order of 10 miles wide the current was flowing southeast in the summer of 1936. His investigation covered a rectangular area extending 100 miles to seaward from the west coast of Vancouver Island. Good-

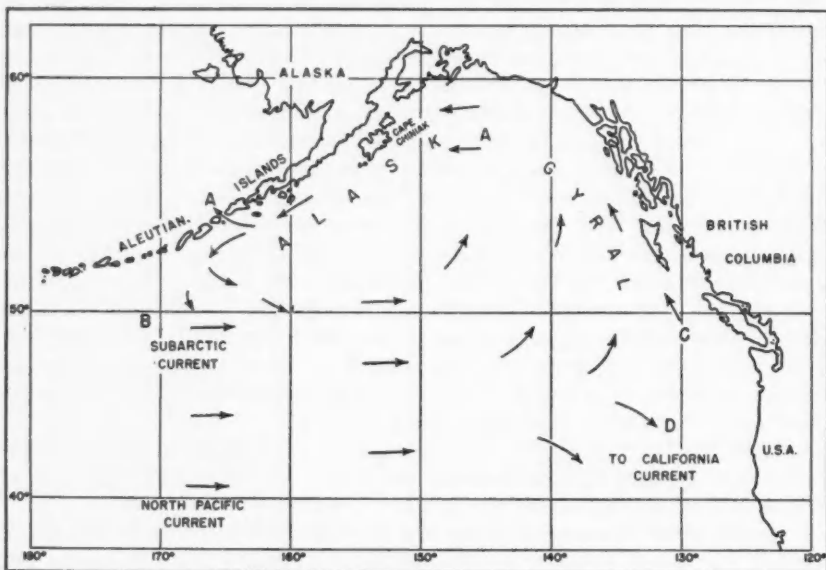


FIGURE 18. Schematic diagram of currents in the Northeast Pacific Ocean and the Gulf of Alaska.

man and Thompson (1940) as stated previously, calculated that the current had a northerly component across the *Oglala* section everywhere except adjacent to the coast, where the flow was southward.

In Figure 12 the calculated currents in both August 1950 and August 1951 include a large eddy west of Juan de Fuca Strait which results in a southeast current off the coast of Vancouver Island. This eddy, if it is of regular occurrence in summer, could account for the southward-flowing current observed by all of the above investigators, and would explain the apparent contradiction between some of their various conclusions and those inferred from this investigation.

These conclusions are strikingly confirmed in Figure 19. Here the data observed in August 1950 during cruise 17 of the Marine Life Research Program (Scripps, 1951) were combined with our August 1950 data by J. L. Reid of the Scripps Institution. This figure is the first quasi-synoptic representation of the general summer surface-current system off the North American coast based upon dynamic computations.

Evidently at that time the Sub-Arctic Current approached the continent between Latitude 45° and 50° N. East of Longitude 140° W. it divided, part turning north to form the Alaska Gyral, and the remainder turning south to form the California Current. Off the British Columbia coast there was a region of eddies and indeterminate movements which coincided with the region of our surveys.

It is regrettable that our other surveys were not coordinated more closely with the cruises of the Marine Life Research Program so that a seasonal series of current diagrams such as Figure 19 could have been prepared. No doubt such a series would have defined the region of divergence in the several seasons and years, and possibly permitted a correlation with the meteorological data. However, we are fortunate to have this one Figure which suggests why the currents are weak and variable off the British Columbia coast, and points to the probable nature of the annual and seasonal variations.

Important differences exist between the conditions observed in the summers of 1950 and 1951 which must be related to the circulation of the water. The dynamic computations and the isentropic analysis point to the conclusion that the water entered this area from a more southerly direction in 1951 than in 1950, which would suggest that the division of the Sub-Arctic Current was farther south in the latter year.

Five-day mean atmospheric pressure charts have been provided by courtesy of the Canadian Meteorological Service at Vancouver, B.C., for a period of three months during and preceding each of these cruises. A preliminary comparison of these charts shows that there were more cyclones in the Gulf of Alaska, and that the North Pacific high-pressure area occupied a mean position farther south in the summer of 1950 than in the summer of 1951. Consequently the wind blew more consistently from the northwest over the whole area in the latter year, as already indicated in Figure 2 for the west coast of Vancouver Island. Therefore, the division between winds with a northerly component and those with a southerly component was farther south in 1950. This is in contrast

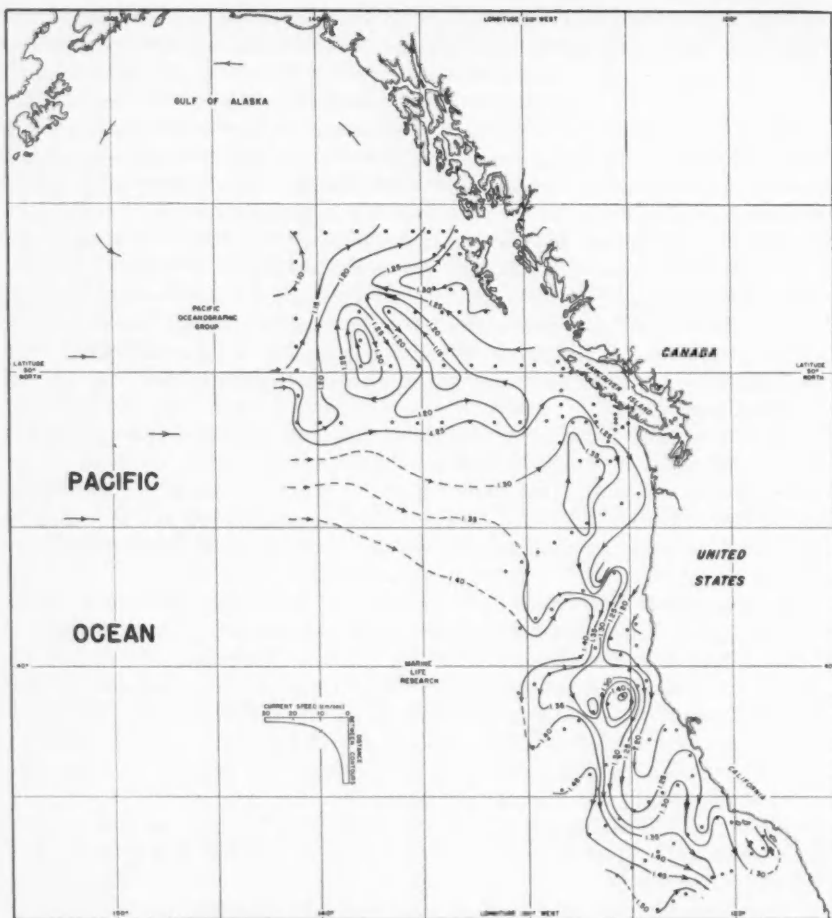


FIGURE 19. Anomaly of dynamic height from the August 1950 survey of the Pacific Oceanographic Group and cruise 17 of the Marine Life Research Program (Scripps Institution of Oceanography, 1951).

with the apparent division of the Sub-Arctic Current which was, by inference, farther south in 1951. Thus the explanation of the differences observed between the currents and surface temperatures in the two years is not immediately apparent in terms of the wind fields.

LOWER ZONE

In the lower zone the water off the coast of British Columbia is intermediate between Aleutian water, as represented by *Bushnell* (a) (Fig. 17) and a more

southern water as represented by *Bushnell* (h), or *Black Douglas* 40.50. *Bushnell* (d) is similar to the British Columbia offshore region. Water of this type probably occupies a band extending eastward from Longitude 175° W., between the Latitudes 45° and 50° N., and represents the mixing of "southern" and Aleutian waters in the Sub-Arctic Current.

Comparison of our data with the *Oglala's* suggests that the lower-zone mid-gulf water did not intrude into the offshore region in 1936 as it did in 1950 and 1951. In the surface zone, on the other hand, the mid-gulf water intruded farther into the offshore areas in 1936 than in these later years.

The evidence already presented indicates that there is a movement of water through the British Columbia Pacific area from south to north. The isentropic charts of the deep water of all the cruises suggests also that a mass of colder water is pressing in toward the northeast and mixing with the southern-type water of the coastal region. Thus it appears that the movement of water indicated by the distribution of properties beneath the halocline is similar to that indicated in the upper zone, but with a larger proportion of water moving along the coast from the south. The region adjacent to the coast contains the highest proportion of southern-type water, some of which may represent an extension of the northward movement observed off the coast of California by Sverdrup and Fleming (1941). From the maximum concentration of southern water near the coast there is a gradual transition through the coastal and offshore regions to the mid-gulf water. The division between "offshore" and "mid-gulf" regions occurs principally west of Longitude 141° W., as a discontinuity in the properties of the stream presumably due to the confluence of waters from its various sources. The offshore region resembles *Bushnell* (d) and (e), and the coastal region resembles *Bushnell* (f), (g) and (h). The properties of the mid-gulf region are intermediate between those of *Bushnell* (a), (b), (c) and (d), (e). This agrees well with the supposition that the northern portion of the stream which crosses the *Bushnell* line flows north past British Columbia. The northern edge of the stream would become the western edge as it turned north. Mid-gulf water would be a mixture of those components weighted in favour of the most northerly types. The southern-type water observed in the coastal region is probably derived in part from the more southerly elements of the Sub-Arctic Current, which would be indistinguishable from similar water moving south off the coast of the United States in the California Current, and in part from water moving north closer to the coast.

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Distribution, Age and Growth of Eastern Pacific Albacore (*Thunnus alalunga* Gmelin)¹

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ABSTRACT

Seasonal and regional variations in the abundance of albacore during the 1949, 1950 and 1951 British Columbia fishing seasons suggest that exploitable stocks occurred in increasingly northerly areas during July and August and in more southerly areas during late August, September and early October. Catches were composed of four length-groups with average lengths of 54.3, 62.9, 71.7 and 81.9 centimetres. These groups were sometimes fairly discrete, but usually overlapped broadly, so that it was necessary to plot frequency distributions on probability paper in order to choose the best points of separation.

Concentric marks on the centra of vertebrae were used as indicators of the age of the fish. The relationship of body length to vertebral radius is rectilinear. There is good agreement between the estimated average length and standard deviation in length of the fish when grouped by length and when grouped by vertebral ring number. The ages indicated for the four groups are III, IV, V and VI; however the first vertebral ring is somewhat less clear than the others and if it were discounted these ages would be reduced by one year. The fish whose vertebrae were examined had almost completed a year's growth.

The length-weight relationship is expressed by the formula, $\log W = -4.912 + 3.13 \log L$, where W is the weight in kilograms and L is the fork length in centimetres.

INTRODUCTION

The seasonal course of development of the fishery suggests that the albacore (*Thunnus alalunga*) may migrate northward along the Pacific coast of North America during late spring and summer. The difficulties of capturing and marking this species in sufficient numbers have prevented the use of tagging to study migration or growth.

Information on related species has been obtained by methods other than marking. Sella (1930) established the distribution of the bluefin tuna (*Thunnus thynnus*) in the Mediterranean and Eastern Atlantic waters by recording commercial hook recoveries. In the same paper he presents the growth rate of the species based on the examination of vertebrae. Aikawa and Katô (1938) studied the growth of albacore of the Western Pacific by similar methods.

This paper presents the results of an analysis of length frequency distributions of the B.C. albacore catch for 1949-51, and of age determinations made from vertebrae taken in 1950.

LENGTH COMPOSITION

MATERIAL USED

Data on casual samples of the British Columbia albacore catch have been collected since 1941 by representatives of the Fisheries Research Board of

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Canada. Recently these have included length measurements, number and weight of fish caught, location and time of capture, number of hours spent fishing, number of lines trolled, and the names of the vessel and captain. Data collected prior to 1949 have not been used in this analysis because measuring methods were not standardized. The measurements used here were from the tip of the snout to the fork of the tail, taken as the fish lay on a flat measuring board. The work has been based on samples which together comprise about one-tenth of the total annual catch, the number of measurements taken being as follows: 38,418 in 1949; 29,474 in 1950; and 10,524 in 1951. Most individual samples represent the total catch of a boat and vary in size from 20 to 1,341 fish. Those of less than 50 fish make up 5.5% of the total number of samples. Port contact representatives made the measurements and compiled trip reports recording the fishing success on various grounds.

Differences between samples representing the same area and period of capture did not appear to be appreciable for samples of more than fifty fish (Table I).

Supplementary to the length data are the voluntary records submitted by each vessel captain in the form of log-book reports, which provide for records of date, time, position, water temperature, wind velocity and direction, catch, and general information. These records duplicate a portion of those collected by the port representatives but also provide more detailed information that has proved valuable in estimating the availability of albacore with relation to time and location. For the years under consideration the percentage of the total catch reported in the tuna log books and the number of vessels reporting were as follows:

<i>Year</i>	<i>Percentage of catch</i>	<i>No. of vessels</i>
1949	62.2	135
1950	43.3	107
1951	45.8	16

These data were also grouped according to areas of capture and time the fish were delivered.

ANALYSIS OF DATA

LENGTH FREQUENCIES. The length data, when distributed according to area and time, formed polymodal frequency distributions which were divided into normal frequency distributions by the method described by Harding (1949), using probability graph paper developed by Hazen (1913). The application of this graphical method was based on the assumption that the polymodal frequency distributions were composed of natural length-groups and that the lengths contained within each group were distributed approximately normally about the group mean.

Examples of the plots on probability paper are given in Figure 1. The ordinates of the original frequency distribution are expressed as cumulative percentages and plotted at the upper limit of the class interval (solid circles in the diagram), giving a series of two or more straight lines joined by curved con-

TABLE I. Example of the distribution of samples for one area and time period: Columbia River to Destruction Island—4th quarter July, 1950.

Length of fish cm.	Frequency																
	410	135	335	324	393	550	155	835	257	355	151	221	404	361	130	101	134
56	..	..	..	..	..	..	..	1	..	..	..	..	..	..	..	..	..
57	..	..	..	..	..	..	..	3	..	..	..	..	..	..	..	..	..
58	..	..	..	..	..	..	..	5	..	..	..	..	..	..	..	..	..
59	..	..	..	..	..	..	..	23	..	..	..	..	..	..	..	..	..
60	..	..	..	..	..	..	..	28	..	..	..	..	..	..	..	..	..
61	..	..	..	..	..	..	..	26	..	..	..	..	..	..	..	..	..
62	1	..	2	..	..	..	2	1	..	..	..	..	..	..	..	..	..
63	3	..	1	..	..	..	3	15	..	..	..	..	..	..	..	..	..
64	3	1	1	..	..	..	2	10	..	..	..	..	..	..	..	..	..
65	3	3	..	..	..	..	2	20	..	..	..	..	..	..	..	..	..
66	1	..	..	6	..	..	3	24	..	..	..	..	..	..	..	..	..
67	10	..	7	10	..	..	3	46	..	..	..	..	..	..	..	..	..
68	23	8	16	19	..	..	10	77	..	..	..	..	..	..	..	..	..
69	33	5	24	20	..	..	32	104	..	..	..	..	..	..	..	..	..
70	47	14	45	46	..	..	50	20	..	..	..	..	..	..	..	..	..
71	57	16	43	41	..	..	70	93	..	..	..	..	..	..	..	..	..
72	46	18	49	48	..	..	64	96	..	..	..	..	..	..	..	..	..
73	45	15	42	34	..	..	54	80	..	..	..	..	..	..	..	..	..
74	27	4	32	20	..	..	40	46	..	..	..	..	..	..	..	..	..
75	24	13	17	17	..	..	25	32	..	..	..	..	..	..	..	..	..
76	23	9	11	8	..	..	11	14	..	..	..	..	..	..	..	..	..
77	15	4	11	9	..	..	10	12	..	..	..	..	..	..	..	..	..
78	11	..	10	8	..	..	8	18	..	..	..	..	..	..	..	..	..
79	6	3	3	5	..	..	2	3	..	..	..	..	..	..	..	..	..
80	4	1	6	4	..	..	11	10	..	..	..	..	..	..	..	..	..
81	4	1	6	3	..	..	6	13	..	..	..	..	..	..	..	..	..
82	7	2	5	4	..	..	7	13	..	..	..	..	..	..	..	..	..
83	2	..	1	4	..	..	5	5	..	..	..	..	..	..	..	..	..
84	1	2	1	1	..	..	1	3	..	..	..	..	..	..	..	..	..
85	..	..	..	..	..	..	..	1	..	..	..	..	..	..	..	..	..
86	1	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
87	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Total	410	135	335	324	393	550	155	835	257	355	151	221	404	361	130	101	134

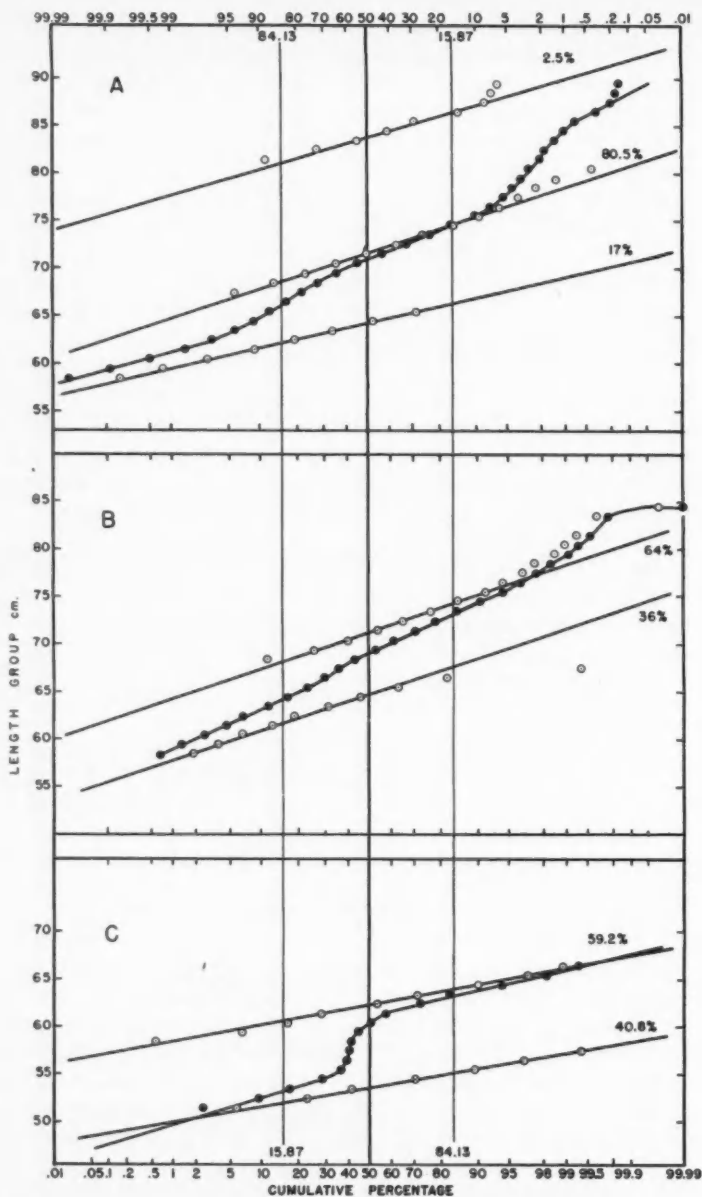


FIGURE 1. Examples of the probability-paper method of fitting normal curves to observed frequency distributions. (A) Destruction Island to Cape Flattery, 3rd quarter of August, 1949. (B) Destruction Island to Cape Flattery, 4th quarter of August, 1949. (C) Cape Mendocino to Cape Blanco, 2nd quarter of October, 1949.

necting sections which represent the region of significant overlapping of the component distributions. The points of inflection on these connecting sections determine the proportion of the distribution that is assigned to each normal curve. In Figure 1B there are two well-defined groups, the smallest consisting of the shortest fish and comprising 36% of the total; there is some evidence of a third group at the other end of the curve, but as the point of inflection lies beyond the 99% point this group seemed too inconsiderable to be separated from the others.

When the component groups were separated as above, each was brought up to terms of 100% frequency, expressed in terms of cumulative percentages, and plotted (open circles in Figure 1). The straight lines joining these points determine normal curves such as are shown in Figure 2; the 50% point (in Figure 1) gives the mean length, and half the difference between the lengths at 15.87% and 84.13% gives the standard deviation in length. Ordinates of the normal curves, for convenient t -values (i.e., distances from the mean, divided by the standard deviation), were obtained from Snedecor's Table 8.5. To put these into terms of the original percentage scale, they were multiplied by n/s , where n is the percentage of the total frequency represented by the particular normal curve and s its standard deviation.

It is appreciated that an albacore population would be unlikely to consist of *completely* normal length-groups, even if each age were sampled in a completely representative manner. In addition, the smallest and largest groups are likely to diverge from normality because of incomplete representation of their smaller and larger members, respectively. However this method of breaking down the multimodal frequency distributions seems justifiable as a simple interpretation of the data available. If the goodness of fit of the combined theoretical dis-

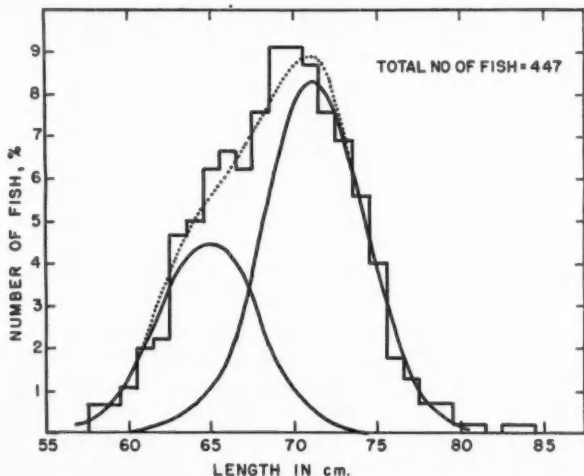


FIGURE 2. Example of the efficiency of fitting normal curves by the probability-paper method. The histogram represents the observed frequencies, and the fitted normal curves are obtained from Figure 1B. The dotted line represents the sum of the two normal curves.

tributions to a whole sample is tested by the χ^2 test, there are small divergences which appear significant when the very large samples of several thousand fish are examined, but there are no deviations which can be detected in samples of less than 1,000 fish. One such test is shown in Table II and Figure 2. The agree-

TABLE II. Test of goodness of fit of normal curves to the frequency distribution shown in Figure 2, based on 447 measurements. Curves B and C are added and extreme values grouped to give 20 class intervals. One degree of freedom is subtracted for each mean, for each standard deviation, for all but one of the component populations, and for the total; this leaves 14 degrees of freedom. Probability of larger χ^2 is P, where $0.95 < P > 0.90$.

Length- groups	Actual frequency	Calculated frequency from normal curves		Combined expected frequency	Difference	(Difference) ² Expected
		B	C			
cm.	%	%	%	%		
53		0.00	...			
4		0.01	...			
5		0.03	...			
6		0.07	...	1.41	0.07	0.0035
7		0.17	...			
8	0.67	0.38	...			
9	0.67	0.75	0.00			
60	1.12	1.33	0.01	1.34	0.22	0.0361
1	2.01	2.12	0.03	2.15	0.14	0.0091
2	2.24	3.04	0.09	3.13	0.89	0.2531
3	4.70	3.92	0.23	4.15	-0.55	0.0729
4	5.15	4.53	0.51	5.04	-0.11	0.0024
5	6.26	4.70	1.05	5.75	-0.51	0.0452
6	6.71	4.39	1.93	6.32	-0.39	0.0241
7	6.26	3.67	3.19	6.86	0.60	0.0525
8	7.61	2.76	4.75	7.51	-0.10	0.0013
9	9.17	1.87	6.36	8.23	-0.94	0.1074
70	9.17	1.14	7.66	8.80	-0.37	0.0156
1	8.73	0.62	8.29	8.91	0.18	0.0036
2	7.61	0.30	8.07	8.37	0.76	0.0690
3	6.94	1.13	7.07	7.20	0.26	0.0094
4	5.59	0.05	5.57	5.62	0.03	0.0002
5	4.03	0.02	3.94	3.96	-0.07	0.0012
6	1.79	0.01	2.51	2.51	0.72	0.2065
7	1.34	0.00	1.44	1.44	0.10	0.0069
8	0.67	...	0.74			
9	0.67	...	0.34			
80	0.22	...	0.14			
1	0.22	...	0.05	1.30	0.92	0.6511
2	0.00	...	0.02			
3	0.22	...	0.01			
4	0.22	...	0.00			
Totals	99.99	36.01	64.00	100.01	...	1.5711

$$\chi^2 = 1.5711 \times \frac{447}{100} = 7.023 \quad \text{d.f.} = 14$$

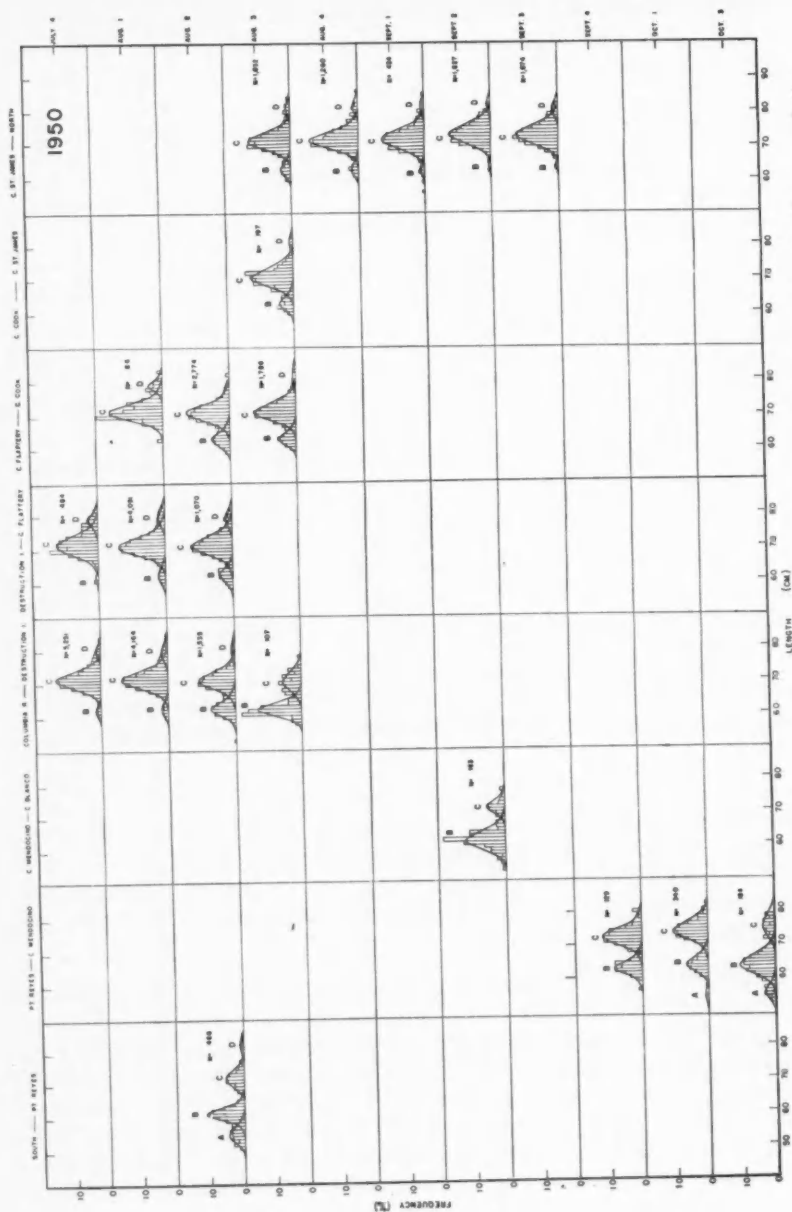


FIGURE 4. Length frequency distribution of the 1950 British Columbia albacore catch by geographical area and time.

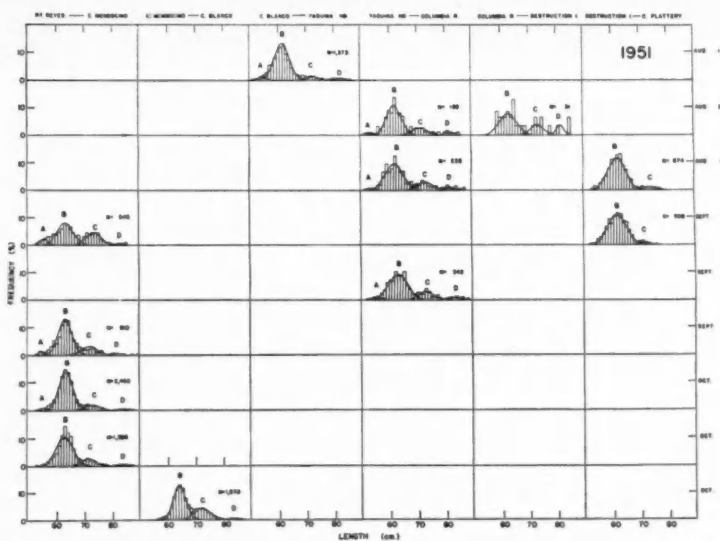


FIGURE 5. Length frequency distribution of the 1951 British Columbia albacore catch by geographical area and time.

calculated for each area and time interval by dividing the total catch in numbers of fish by the total number of hours spent fishing.

In order to compare the availability of each length-group it was assumed that there was no size selection by trolling gear; this seemed reasonable under the conditions of the fishery. The availability for each area and time interval was divided in the ratio of the frequencies of its component length-groups.

SEASONAL AND REGIONAL VARIATIONS

The length frequency data indicate that the exploited stocks of the Eastern Pacific albacore are composed of four natural length-groups, hereafter referred to as A, B, C and D, with average mean lengths of 54.3, 62.9, 71.7 and 81.9 centimetres, respectively. These average mean lengths cover the three years (1949, 1950, 1951) but the yearly mean lengths are relatively close (Table I). Similarly when the mean lengths for each area and time period are compared, only minor differences are found among them (Fig. 3-5).³

³The greatest divergence occurs in the area from Cape Cook to Cape St. James during the first and second quarter of September, 1949, where the mean lengths of group C (Table III) are smaller than expected (Table VI), being 68.7 and 68.4, respectively, as compared with the average value 71.1. Comparison with adjoining areas shows that in the area immediately to the north (north of Cape St. James) the mean for the second quarter of September is 72.5, or greater than the 71.1 of the total catch. While it is possible that the larger fish of this group went farther north and the smaller ones stayed south, these contrasts are more apt to be attributable to the large chance fluctuations which are almost sure to occur in one or two places in any large body of data.

TABLE III
(contd.)

Time	Area	Length-groups																
		Total availa- bility	A				B				C				D			
			%	Mean	S.D.	Availa- bility	%	Mean	S.D.	Availa- bility	%	Mean	S.D.	Availa- bility	%	Mean	S.D.	Availa- bility
1-mos.																		
Oct. 1st	C. Mendocino to C. Blanco	26.42	34.0	52.70	1.02	8.98	66.0	62.18	2.12	17.44	...	...	...	...	...	...	...	...
Oct. 2nd	C. Mendocino to C. Blanco	10.31	40.8	53.65	1.57	4.21	59.2	62.40	1.66	6.10	...	...	...	...	...	...	...	...
Oct. 3rd	C. Mendocino to C. Blanco	6.94	40.8	53.25	1.47	2.83	59.2	62.40	1.70	4.11	...	...	...	...	...	...	...	...

TABLE IV. The percentage composition, mean length, standard deviation, and availability (fish per boat-hour fished) of component length-groups (A, B, C and D) of the 1950 British Columbia albacore catch for selected geographical areas and quarter-month time periods. Total availability estimates by area and time are included.

Time	Area	Total avail- ability	Length-groups														
			A			B			C			D					
			%	Mean <i>cm.</i>	S.D.	Availa- bility	%	Mean <i>cm.</i>	S.D.	Availa- bility	%	Mean <i>cm.</i>	S.D.	Availa- bility			
3 mos. to 4th	Columbia R. to Destruction I.	3.38	...	...	...	5.5	62.25	1.75	0.19	89.0	71.60	2.63	3.00	5.5	80.60	2.30	0.19
	Destruction I. to C. Flattery	3.18	...	...	...	2.0	62.40	1.92	0.06	87.0	71.75	2.90	2.77	11.0	79.15	2.14	0.35
Aug. 1st	Columbia R. to Destruction I.	2.61	...	...	...	7.0	62.68	2.00	0.18	85.5	71.50	2.55	2.23	7.5	79.65	2.29	0.20
	Destruction I. to C. Flattery	2.67	...	...	...	8.0	62.25	1.87	0.21	85.0	71.40	2.55	2.27	7.0	80.20	1.81	0.19
	C. Flattery to C. Cook	2.37	...	...	...	...	...	...	...	88.5	71.50	2.28	2.10	11.7	79.00	1.15	0.27

TABLE IV (contd.)

Time	Area	Length-groups																
		A				B				C				D				
		Total availa- bility	%	Mean cm.	S.D.	Availa- bility	%	Mean cm.	S.D.	Availa- bility	%	Mean cm.	S.D.	Availa- bility	%	Mean cm.	S.D.	Availa- bility
4-moz. Aug. 2nd	South of Pt. Reyes	1.46	23.4	55.00	1.65	0.34	47.6	61.25	1.75	0.69	27.9	71.72	2.34	0.41	1.1	81.95	1.16	0.02
	Columbia R. to Destruction I.	3.21	...	...	...	...	34.0	62.50	1.95	1.09	63.7	71.00	2.47	2.04	2.3	80.00	2.47	0.08
	Destruction I. to C. Flattery	2.45	...	...	...	...	17.0	62.40	1.91	0.42	77.5	71.30	2.75	1.90	5.5	79.70	1.86	0.13
	C. Flattery to C. Cook	2.84	...	...	...	...	24.0	63.10	1.92	0.68	76.0	71.00	...	2.38	2.16	...	...	...
Aug. 3rd	Columbia R. to Destruction I.	0.83	...	...	...	...	63.0	62.05	2.02	0.53	37.0	70.18	2.80	0.13	2.16	...	...	...
	C. Flattery to C. Cook	3.11	...	...	...	...	22.0	62.82	1.82	0.69	75.7	71.00	2.52	2.32	2.3	80.00	2.70	0.07
	C. Cook to C. St. James	2.68	...	...	...	...	18.3	62.90	1.88	0.49	80.2	70.70	2.57	2.15	1.5	81.00	0.70	0.04
Aug. 4th	North of C. St. James	5.53	...	...	...	...	13.5	62.70	2.00	0.75	78.0	71.25	2.45	4.31	8.5	80.75	3.42	0.47
Sep. 1st	North of C. St. James	6.40	...	...	...	...	8.0	62.95	2.05	0.51	86.3	71.25	2.37	5.52	5.8	80.90	1.90	0.37
Sep. 2nd	North of C. St. James	5.17	...	...	...	...	5.0	62.65	1.62	0.26	89.5	71.40	2.80	4.63	5.5	81.10	2.25	0.28
	C. Mendocino to C. Blanco	6.96	...	...	...	...	78.6	61.60	3.74	6.57	31.6	71.70	1.70	1.50	...	...	...	...
Sep. 3rd	North of C. St. James	3.47	...	...	...	...	1.7	62.95	2.00	0.06	91.3	72.80	2.87	3.17	7.0	80.85	2.85	0.24
Sep. 4th	North of C. St. James	3.17	...	...	...	...	1.4	63.30	1.52	0.04	90.6	72.50	2.83	2.87	8.0	80.25	2.35	0.26
	Pt. Reyes to C. Mendocino	6.37	...	...	...	...	34.1	62.50	1.80	2.17	65.9	72.15	2.52	4.20	...	...	...	...
Oct. 1st	Pt. Reyes to C. Mendocino	5.15	1.4	54.10	1.42	0.07	32.6	63.35	1.60	1.68	66.0	73.65	2.67	3.40	...	...	...	...
Oct. 3rd	Pt. Reyes to C. Mendocino	12.72	11.0	54.65	1.72	1.40	69.0	62.75	2.75	8.78	20.0	74.70	2.77	2.54	...	...	...	...

TABLE V. The percentage composition, mean length, standard deviation, and availability (fish per boat-hour fished) of component length-groups (A, B, C and D) of the 1951 British Columbia albacore catch for selected geographical areas and quarter-month time periods. Total availability estimates by area and time are included.

Time	Area	Total availability	Length-groups															
			A			B			C			D						
			%	Mean	S.D.	Availability	%	Mean	S.D.	Availability	%	Mean	S.D.	Availability				
			cm.		cm.		cm.		cm.		cm.		cm.		cm.			
Aug. 1st	C. Blanco to Yaquina Hd.	2.01	6.0	54.50	1.69	0.12	82.0	61.40	2.50	1.65	8.0	72.00	2.33	0.16	4.0	81.95	2.88	0.08
Aug. 2nd	Yaquina Hd. to Columbia R.	4.71	1.8	53.25	1.08	0.08	74.7	61.70	2.70	3.51	18.5	70.75	2.70	0.87	5.0	81.70	1.80	0.24
	Columbia R. to Destruction R.	0.52	...	...	...	...	65.5	62.80	3.25	0.34	23.0	73.25	2.35	0.12	12.0	81.65	1.25	0.06
Aug. 4th	Yaquina Hd. to Columbia R.	1.78	1.4	54.15	1.33	0.02	74.6	61.65	3.13	1.33	20.5	72.90	2.73	0.37	3.5	81.75	1.25	0.06
	Destruction I. to C. Flattery	3.98	...	...	...	...	93.0	61.85	3.20	3.70	7.0	73.05	2.78	0.28	...	...	...	...
Sep. 1st	Pt. Reyes to C. Mendocino	1.79	8.0	55.50	1.50	0.14	57.0	63.00	2.80	1.02	32.3	73.30	2.70	0.58	2.7	83.00	1.72	0.05
	Destruction I. to C. Flattery	3.47	...	...	...	...	94.5	61.70	3.40	3.28	5.5	71.20	2.23	0.19	...	...	...	...
Sep. 3rd	Yaquina Hd. to Columbia R.	2.56	2.0	54.50	1.10	0.05	75.0	62.80	3.25	1.92	18.0	72.75	2.50	0.46	5.0	83.30	2.55	0.13
Sep. 4th	Pt. Reyes to C. Mendocino	0.93	3.5	54.60	0.90	0.03	78.5	63.00	2.45	0.73	16.6	71.80	2.20	0.15	1.0	80.60	1.05	0.02
Oct. 1st	Pt. Reyes to C. Mendocino	5.33	2.0	54.95	1.40	0.10	83.9	63.05	2.40	4.47	12.8	72.25	2.75	0.68	1.3	83.10	3.70	0.08
Oct. 2nd	Pt. Reyes to C. Mendocino	8.81	...	...	...	...	81.0	62.85	3.07	7.14	17.3	71.60	2.78	1.52	1.7	84.50	2.75	0.15
Oct. 3rd	C. Mendocino to C. Blanco	0.58	...	...	...	...	70.5	63.90	2.23	0.41	28.5	71.85	2.80	0.16	1.0	82.55	2.05	0.01

TABLE VI. Percentage composition, mean length, standard deviation, standard error of the mean, and availability (fish per boat-hour fished) of component size-groups of the 1949, 1950 and 1951 British Columbia albacore catches. Total availability estimates for each year are included.

Year	Total availability	Size-group	Percentage composition	Mean length	S.D.	S.E.	Availability
				cm.			
1949	5.04	A	3.05	53.25	1.35	0.040	0.15
		B	28.95	63.30	2.07	0.020	1.46
		C	65.50	71.10	2.82	0.018	3.30
		D	2.50	82.95	2.87	0.093	0.13
1950	3.39	A	0.40	54.27	1.75	0.160	0.01
		B	11.90	62.35	2.05	0.030	0.40
		C	80.70	71.35	2.62	0.017	2.74
		D	7.00	79.70	2.37	0.05	0.24
1951	2.19	A	3.50	55.25	1.65	0.086	0.08
		B	81.50	62.90	2.75	0.029	1.78
		C	13.10	72.75	2.75	0.074	0.29
		D	1.90	82.95	3.02	0.214	0.04

It is not possible to demonstrate that the size of the fish within a group varies significantly with latitude. Also, there was no marked increase in length, with time, over the period for which samples were obtained in any year. This would indicate a slow growth rate at this time of year, if there is any considerable continuity in the stock available throughout the season. The latter condition would of course require confirmation.

Although the groups A, B, C and D, when present, are always centred about approximately the same mean lengths, their relative proportions vary within the season, among fishing areas, and between years (Tables III-VI, Fig. 3-6). The catch-per-unit-of-effort data indicate how these changes in the relative proportions of the length frequency distributions are related to changes in fish abundance on the fishing grounds. From them it may be determined whether a *relative* increase of a particular class is caused by an influx of fish belonging to that class or merely shows that the fish belonging to other classes have left the area. The importance of a particular class may be readily assessed by comparing its availability for a particular area and time with the average for that class over the whole period (Table IV).

In general, the seasonal and regional variations of length-group abundance indicated an increasingly northerly occurrence of exploitable stocks during early periods of the fishing season and an increasingly southerly occurrence during later periods. The larger fish (groups C and D) precede the smaller fish (groups A and B) in the northern areas of the fishery, and the smaller fish disappear from the northern areas first. However, near the end of October on southern fishing grounds the larger length-groups disappeared from the fishing areas sooner than the smaller length-groups (Fig. 3-5). This pattern is consistent with

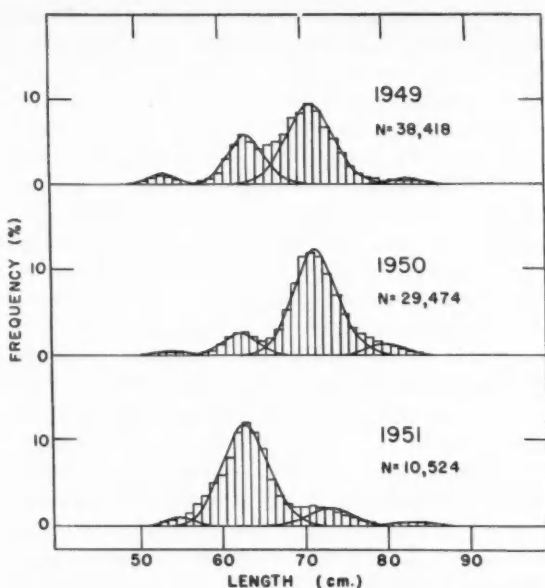


FIGURE 6. Comparison of length frequency distributions of the 1949, 1950 and 1951 British Columbia albacore catches.

a theory of along-shore migration of the stocks, northward in early summer and southward later; but it would not preclude other possibilities, such as seasonal movements toward the coast of sections of a stock normally present farther off-shore.

Albacore occurred in the area between the Columbia River and Destruction Island during the last week of July, but were not captured in the area north of Cape St. James until the third or fourth quarter of August. The occurrence of the smaller length-groups in the southern areas coincided with their gradual decrease in abundance in the northern areas later in the fishing season (end of August and beginning of September). The larger size-groups were not abundant in areas adjacent to California until after the cessation of fishing in areas adjacent to British Columbia, in the third and fourth periods of September.

Movement of the stocks is most strongly suggested by the availability figures for 1950 (Table IV). In the area north of Cape St. James the availability of classes B, C and D was above the year's average during the third and fourth periods in August. The availability of groups C and D continued to be high for the first three periods in September. The availability of group B fell below the average in this area, but was as high as 6.57 in the southern area (between Cape Mendocino and Cape Blanco) in the second period of September.

During 1949 and 1950 the larger length-groups (C and D) dominated the catches in waters adjacent to the state of Washington until mid-August. With

few exceptions, group B increased in relative numbers with the advance of the season in all areas between the Columbia River and Cape St. James. At any given time, its percentage contribution decreased progressively from south to north. The reverse was of course observed for length-groups C and D.

In the area south of the Columbia River only length-groups A and B were represented during the later periods of the 1949 fishing season; of these the larger fish (group B) decreased in relative numbers as the season advanced. Similarly in 1950, when groups B and C were the important ones south of the Columbia, the larger fish (group C) showed an early increase in relative numbers after cessation of fishing north of the Columbia, but decreased in relative abundance in areas adjacent to California just before the end of the season. This late increase in relative abundance of groups B and C in the southern areas, in 1949 and 1950, respectively, and the failure of groups C and D to return to southern fishing areas after fishing ceased north of the Columbia River in 1949, suggest that groups C and D leave the fishing areas earlier than do groups A and B.

The smallest length-group (group A) was never found in the catches north of the Columbia River. Furthermore, group B gradually decreased in relative abundance northward, and approached the northern limit of its occurrence in the area immediately north of Cape St. James.

Unfortunately, inadequacies in the coverage of areas by the 1951 fishery did not permit a comprehensive picture of albacore distribution to be obtained in that year. There was only scattered fishing north of Cape Flattery, so no usable information was obtained from the three northern areas. A peculiarity of the year is the fact that, contrary to observations in the two previous years, there was no decrease in the abundance of the larger fish just before the termination of the fishing season.

DIFFERENCES BETWEEN YEARS

In 1949 and 1950 length-group C was the dominant group in the fishery but in 1951 length-group B was relatively more abundant (Table VI, Fig. 6). Since in 1949 and 1950 the relative abundance of groups C and D in the northern areas of the fishery was greater than in more southern areas, the absence of catches north of Cape Flattery in 1951 might be related to the relative scarcity of these groups in the totals for the year.

In addition, or alternatively, change in the environment may have been a factor contributing to the decline in availability and to the change in distribution of albacore during 1951, as compared with the two previous years. During the 1950 fishing season the relatively warm body of water normally inhabited by albacore was confined to a narrow band parallel to the coast of British Columbia (Waldie and Doe, 1950); it was 20 miles wide and close to shore in the region of the Queen Charlotte Islands and 120 miles wide but farther from shore near the southern extremity of British Columbia. During 1951, however, this body of water was found to extend at least 650 miles true west from the coast of southern British Columbia (Doe, 1951). Since the Canadian fishing fleet is limited in the distance it may safely operate from shore,

it may be concluded that only a small portion of the water favourable for albacore was covered. Accordingly, the observed decrease in availability and the change in distribution of the albacore population may have been caused by the dispersal of previously exploitable stocks over a greater area than during the two previous years.

AGE COMPOSITION

MATERIAL AND METHODS

Vertebrae from 531 fish captured during the 1950 fishing season were collected at processing plants in Vancouver, B.C., during the winter of 1950-51. The ninth prehaemal vertebra was selected for study. Selection of this thoracic vertebra was based on its accessibility, uniformity of shape, and the legibility of the concentric rings on its centrum. Body lengths (i.e. fork lengths) were measured from the tip of the snout (most anterior part of the upper jaw), when the jaws were closed, to the cartilaginous median part of the caudal fork (Marr and Schaefer, 1949). Weights of 505 of the 531 albacore sampled were determined to the nearest ounce using a Chatillon spring scale.

The material was considered to be reasonably representative of the 1950 albacore population from offshore waters adjacent to California, Oregon, Washington and British Columbia. Some size selection may have occurred when cannery operators removed the fish from cold storage for processing, but it was assumed that size selection by fishing gear did not occur. No allowance was made for possible shrinkage caused by freezing the catch.

The length data were segregated into normal frequency distributions as for the general sample. This was done in order that the vertebral ring-classes could be compared with those of the natural length-groups of both the vertebral sample and the larger sample of the year's catch used for the length analysis in the previous section.

Sectioning of vertebrae and accentuation of growth rings on the centra facilitated vertebral examinations. Each vertebra was sectioned in the horizontal plane into two unequal segments with the aid of a fine-toothed circular saw. The larger segment was ground on a motor-driven disc sander until the centre of the centrum was revealed. Growth rings were accentuated by immersing the vertebrae in 1% KOH for 36 hours, washing in tap water, and preserving in 95% alcohol (Fig. 7-9; these show sagittal sections).

The amphicoelus albacore vertebra, sectioned in the above manner, reveals two hollow cones whose vertices meet at the centre of the centrum and whose bases form the anterior and posterior margins of the vertebra. Upon the inner surface of these cones are complete rings running parallel to the base of the cone and encircling the centrum. They are narrow translucent zones separated by broad opaque zones similar to those described by Freidenfelt (1922) for *Lucioperca*. In the albacore the narrow zones were observed not only as translucent bands but also as eruptions or ridges on the centrum surface. The innermost ring differed slightly from the others but was nevertheless clearly marked. Ring measurements were made to the midpoint of each ridge.

Vertebral rings were measured by the method developed by Freidenfelt



FIGURE 7. Albacore vertebra, sagittal section, prior to treatment.

(1922) and applied to scombrids by Aikawa and Kato (1938). Vertebrae were examined by reflected light using a microscope having $12\times$ magnification. The sectioned surface of each vertebra was placed in contact with the under surface of the glass stage. Measurements were made to the nearest tenth of a millimetre, with the aid of a rule graduated in 0.5-millimetre intervals, which was placed below the glass stage. The distances from the centre of the centrum to each ring and to the outer edge of the centrum were measured along the four exposed edges of the cones. Corresponding measurements were averaged. These average measurements are referred to as ring radii and vertebral radii, respectively.



FIGURE 8. Albacore vertebra, sagittal section, after 36 hours in a 1% KOH bath.

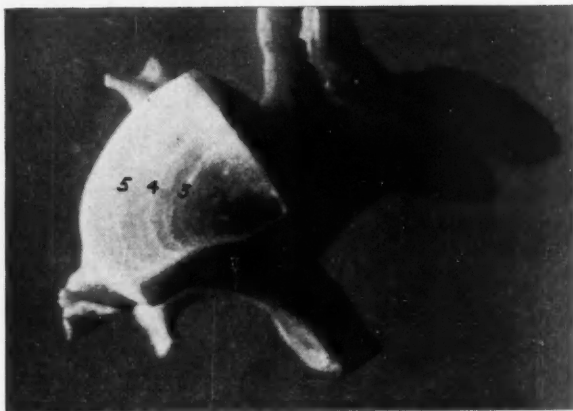


FIGURE 9. Albacore vertebra, sagittal section, after fixation in 95% alcohol. The numerals designate annuli.

RELATIONSHIP OF FORK LENGTH AND VERTEBRAL RADIUS

Prerequisite to growth calculations based on measurements of a skeletal part is the establishment of a definite relationship between the growth of the part and the growth of the entire body. In the present study the radius of the ninth prehaemal vertebra was compared with fork length for 200 fish throughout the range of sizes represented in the entire sample. The vertebral radii were plotted arithmetically against the fork lengths and a rectilinear regression was calculated by the method of least squares (Fig. 10), thus:

$$R = -0.069 + 0.127L,$$

where R is the vertebral radius in millimetres and L is the fork length in centimetres. As the line passes very close to the origin and as the data do not give any values for fish of less than 50 cm. to confirm the extrapolation to the axes, it is assumed in subsequent calculations that vertebral radius and fork length are directly proportional at all sizes.

AGE DETERMINATIONS

In order to establish that vertebral rings were true year marks the data were examined in several ways. Counts of rings were reproducible with high consistency. If they are year marks, and if the natural length-groups also represent age-groups, there should be agreement between (1) the mean length of fish assigned to each vertebral ring-class and the mean length of corresponding length-groups in the sample, and (2) the lengths of young fish calculated from vertebral measurements of older fish, and the observed lengths of young fish.

Comparison of mean lengths of component length-groups with mean lengths of ring-classes in the vertebral sample showed acceptable agreement (Fig. 11, Table VII). Agreement was also observed between the mean lengths of com-

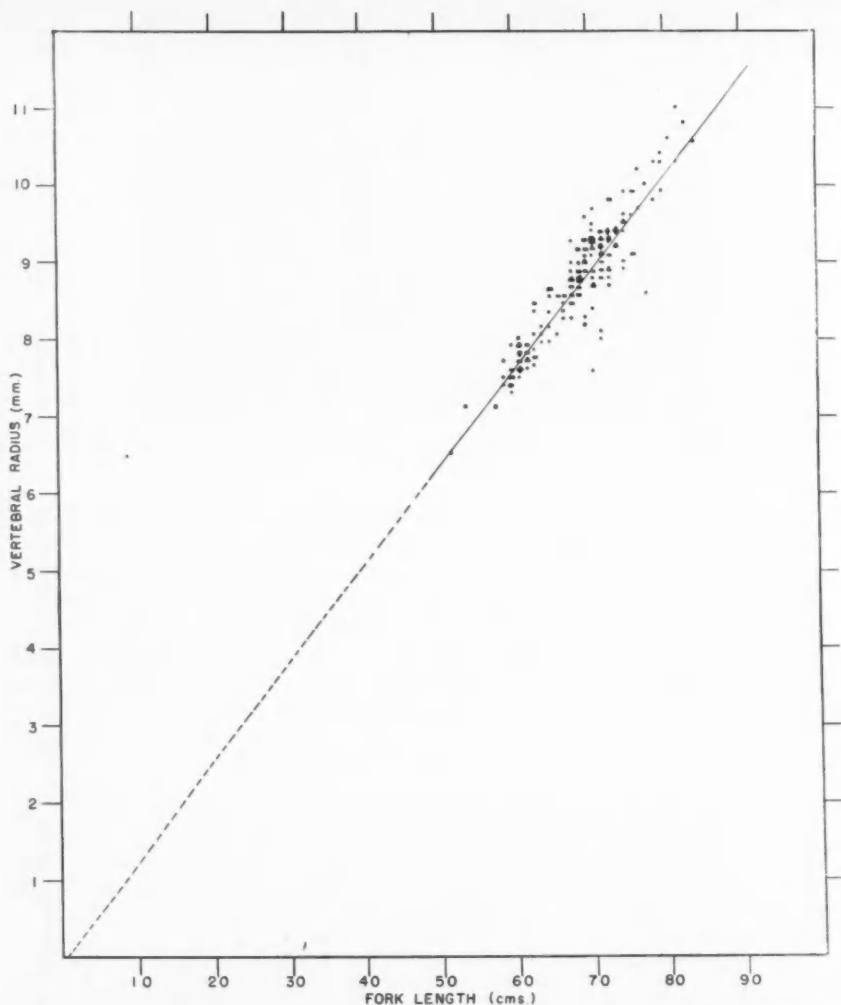


FIGURE 10. Relationship between fork length and vertebral radius of Eastern Pacific albacore; sampled from the 1950 British Columbia commercial catch.

ponent length-groups of the vertebral sample and those of the larger sample of the 1950 catch used in the previous section (Table VII).

Lengths at the time of vertebral ring formation calculated from vertebral radius measurements were compared with observed lengths of fish of each ring-class at time of capture, for a subsample of 98 albacore (Fig. 13, Table VIII).

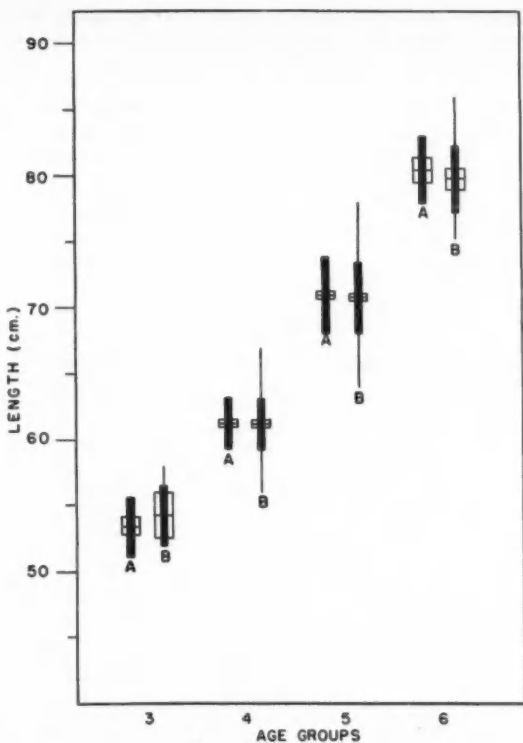


FIGURE 11. Comparison of component length-groups (A) and assigned age-classes (B) in the vertebral sample. The vertical line represents the length range; the solid rectangle represents two standard deviations, the light rectangle represents two standard errors on either side of the mean described by the horizontal line within the light rectangle.

There was good agreement, although of course the observed lengths were consistently greater than the calculated lengths because the fish were captured some time after the last ring was formed. One discrepancy occurred in the data: the average length at capture of fish having four vertebral rings slightly exceeded the average calculated length at the formation of the next growth ring, but there are only five 4-ring fish. Fish with three vertebral rings were not represented in the subsample of vertebral data used for these calculations.

From the above it seems clear that the third and subsequent vertebral rings are produced annually. It is assumed, in the absence of contrary evidence, that the inner two rings are annual also. Subsequent reference to ring-classes 1-6 will be expressed as "assigned age-groups I-VI." Similarly length-groups A, B, C and D, described earlier in this paper, will be expressed as age-groups III, IV, V and VI.

TABLE VII. Comparison of the percentage composition and mean length of assigned age-groups in the vertebral sample with component size-groups in the vertebral sample and with component size-groups in the commercial catch sample (1950).

Vertebral Sample				
Assigned age-groups	Percentage of total distribution	Mean length	Standard deviation	Standard error
		<i>cm.</i>		
III	1.3	54.28	2.21	0.83
IV	29.6	61.22	1.90	0.15
V	61.6	70.83	2.70	0.15
VI	7.5	79.85	2.54	0.40
Vertebral Sample				
Component size-groups	Percentage of total distribution	Mean length	Standard deviation	Standard error
		<i>cm.</i>		
A	1.1	53.40	2.20	0.29
B	30.9	61.30	1.95	0.15
C	62.0	71.00	2.87	0.16
D	6.0	80.55	2.52	0.45
Commercial Catch				
Component size-groups	Percentage of total distribution	Mean length	Standard deviation	Standard error
		<i>cm.</i>		
A	0.4	54.27	1.75	0.16
B	11.9	62.35	2.05	0.03
C	80.7	71.35	2.62	0.02
D	7.0	79.70	2.37	0.05

GROWTH RATE

GROWTH IN LENGTH

Once it has been established that the ring-classes are annual, the calculated lengths for each year of life give an estimate of the growth rate. The slope of the curve in Figure 13 and the increments given in Table VIII show that although growth in length is almost linear there is a slight decrease with age, as would be expected.

The subsample of 98 fish did not contain any III-year-olds but the average length at capture for the whole vertebral sample is available for comparison (values from Table VII are repeated in Table VIII). Considering the two central well-represented groups, IV and V, these observed lengths exceed the average calculated lengths by about three quarters of the annual increments, indicating that most of the annual growth had occurred before capture. (Slow growth during the fishing season was also surmised from the stability of the means of length-groups throughout the season.) The large observed value for age-group III, 54.3 cm., which exceeds the calculated length for age-group

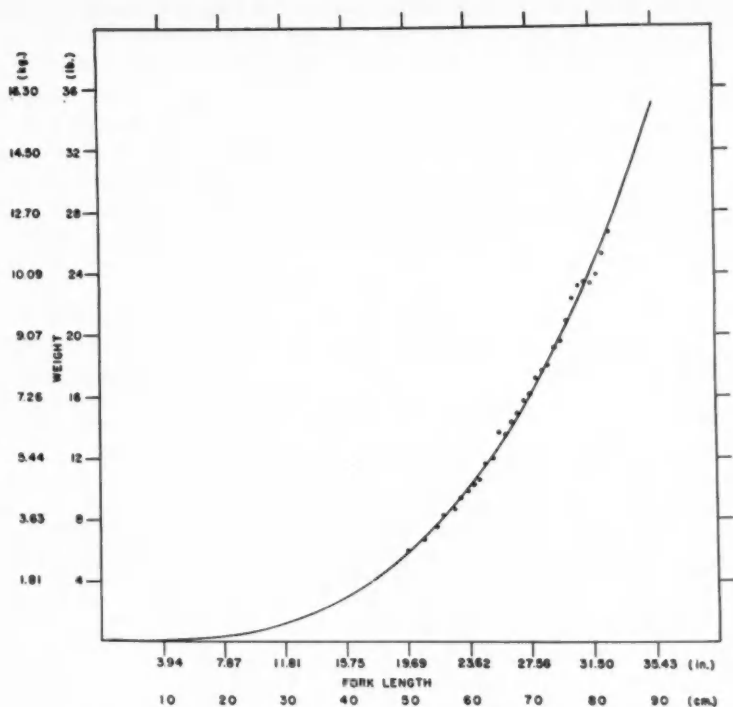


FIGURE 12. Showing the fit of the calculated length-weight curve (solid line) to the measured data (dots). Sample taken from 1950 Eastern Pacific albacore.

TABLE VIII. Calculated fork length, in centimetres, at time of vertebral annulus formation for a small sample of 1950 albacore whose age has been assigned by ring-class determinations. (The calculation was made by assuming direct proportionality between fork length and vertebral growth for each fish.) The average length at capture of the whole vertebral sample (Table V) is included for comparison.

Age-group	No. of fish	Average length at capture	Length at ages indicated					
			I	II	III	IV	V	VI
IV	5	63.0	15.4	26.4	39.9	52.9	...	...
V	85	70.8	15.1	27.3	39.6	52.0	62.8	...
VI	8	79.6	15.7	28.7	40.8	53.3	64.3	72.1
Average calculated length (weighted)			15.2	27.3	39.7	52.2	62.9	72.1
Average annual increment			15.2	12.1	12.4	12.5	10.7	9.2
Average length at capture, whole vertebral sample					54.3	61.2	70.8	79.9
(Nos. of fish in brackets)					(7)	(157)	(327)	(40)

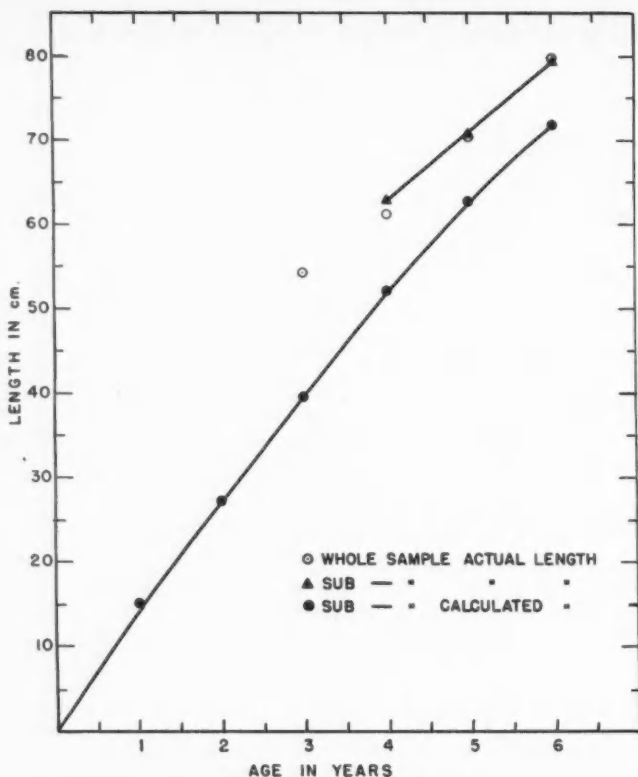


FIGURE 13. Showing agreement between the mean length of albacore each year calculated from vertebral ring radius by assuming direct proportionality (solid circles), and the actual mean lengths at time of capture. Ring radii were measured on a subsample of 98 fish; actual lengths were obtained from both this subsample (triangles) and from the whole vertebral sample of 531 fish (open circles).

IV at time of ring formation, 52.2 cm., might be only a sampling effect, since there were few III's in the total sample. However it is more likely to reflect a scarcity of the smaller fish of this age in the fishery, to which may be related their limited northern occurrence (see length-group A, Table IV).

No division of the data was made on the basis of sex differences. According to Brock (1943) the sex ratio of albacore closely approximates one to one, and no significant difference in length occurs between the sexes. It was assumed that this condition holds for the albacore population under investigation.

COMPARISON WITH WESTERN PACIFIC ALBACORE

The growth estimates above are at a variance with those observed by Aikawa and Katô (1938) for albacore of the Western Pacific. A comparison of

vertebral ring radii (Table IX) shows that those of the eastern stocks are consistently 1.4–1.5 mm. less than those of the western stocks for each age-group up to the fifth, with the exception of the first where the difference is 1.3 mm. If the radii for the western stocks are compared to those for ring-classes *one ring lower* in eastern albacore there is very close agreement: hence possibly Aikawa and Katô did not recognize, or did not accept as an annulus, the first ring measured in this study. No independent evidence is available in either study to corroborate the estimate of first-year growth, but the certainty with which later rings are established as annual makes it likely that our ring I has a similar origin.

LENGTH-WEIGHT RELATIONSHIP

Weights and lengths of both sexes were used to determine the weight-length relationship:

$$\log W = -4.912 + 3.13 \log L,$$

where W is the weight in kilograms and L is the fork length in centimetres.

The above relationship is shown as a curve in Figure 12, where the average weight of fish at each centimetre of length is shown for the 1950 sample. The greatest difference between actual and calculated weight occurs at lengths that are poorly represented in the data. The observed average weights of age groups are:

Age	Weight	
	kg.	lb.
III	3.43	7.56
IV	4.72	10.41
V	6.73	14.83
VI	10.72	23.64

SUMMARY

In offshore waters adjacent to Canada the albacore formed the basis of a commercial fishery during the summer months of July, August and September, 1949–51. It was also encountered in more southerly waters later in the year. In general, the seasonal and regional variations of length-group abundance suggest a progressive northward occurrence of available stocks until mid-August, after which a southward progression occurs. In the northern areas the

TABLE IX. The average vertebral ring radius in millimetres at annulus formation in Eastern and Western Pacific albacore stocks. Data for western stocks are from Aikawa and Katô (1938, p. 79).

Age-class	Average vertebral ring radius							
	I	II	III	IV	V	VI	VII	VIII
Eastern	1.9	3.4	5.0	6.5	7.9	9.1	...	...
Western	3.2	4.9	6.4	7.9	9.4	11.0	12.7	14.2

larger (older) fish appear in abundance before the smaller (younger) fish, but the reverse situation occurs when the fishery is falling off in these areas and increasing in southern areas. Of the four length-groups which make up the exploitable population, the smallest (youngest) is not encountered north of the Columbia River. Environmental changes which occurred over the years studied may have contributed to the observed decline in average abundance from 5.04 fish per boat-hour fished in 1949 to 2.19 in 1951.

Vertebral age determinations of British Columbia albacore indicate that four age-groups are involved. These are provisionally identified as 3-, 4-, 5- and 6-year-old fish, which attain respective mean lengths of 39.7, 52.2, 62.9 and 72.1 cm. (Table VIII) at time of annulus formation, and 54.3, 61.2, 70.8 and 79.9 cm. (Table VII) at time of capture. The rate of growth in length decreases slightly with increasing age, and weight increases at a rate greater than the cube of the length.

ACKNOWLEDGMENTS

The writer is indebted to Messrs. R. M. Wilson, D. Odum and R. J. Karjala, who assisted in collecting samples. Catch samples were obtained through the courtesy of Tullock Fisheries Ltd. and Canadian Fishing Company Ltd. Aid in statistical analysis by Dr. W. E. Ricker and Miss Y. M. M. Bishop, and the ready co-operation of other staff members of the Pacific Biological Station are gratefully acknowledged.

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Histological Studies on Albacore (*Thunnus alalunga*) Gonads from the Eastern Pacific¹

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ABSTRACT

Sections of testes and ovaries from 44 fish showed maturing individuals in age-groups V and VI, but none in IV. There was no evidence of previous spawning.

INTRODUCTION

PARTLO (1954) identified modes in the length frequency of samples of albacore catches taken in the Eastern Pacific with age-groups III to VI by graphic analysis and by counting rings on vertebral centra. His age designations are used here. Further information on the life history can be obtained by an histological examination of the gonads.

Some information is available in the literature concerning the seasonal changes in the gonads of a number of species. Hann (1927) deals with those of *Cottus* and James (1946) with the bluegill and largemouth bass.

DEVELOPMENT OF THE GONADS

Gonads from a series of 44 fish of ages IV, V and VI (Table VII, p. 56) were collected, fixed in Bouin's fluid, sectioned and stained by routine haematoxylin and eosin techniques. Sections selected from anterior, medial and posterior segments of each gonad were studied.

The gonad in both sexes is suspended in the posterior part of the body cavity by its mesentery and is associated with a fat body (Godsil and Byers, 1944).

THE MALE GONAD

The male gonad is suspended by the mesorchium and its products are collected by a series of small ducts leading to a large gonoduct (Fig. 1-4). The homology of these ducts is at present uncertain but, on a functional basis, they will subsequently be referred to as vasa efferentia and vas deferens respectively.

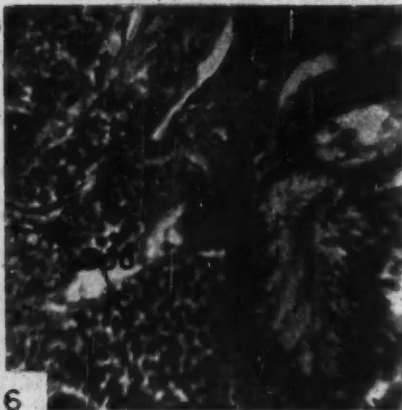
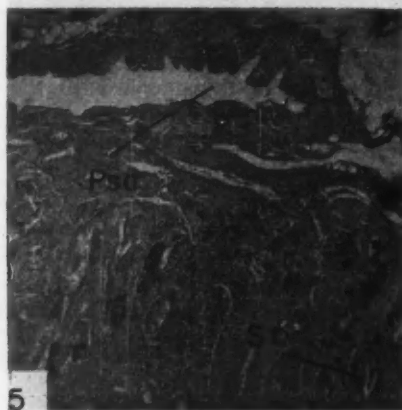
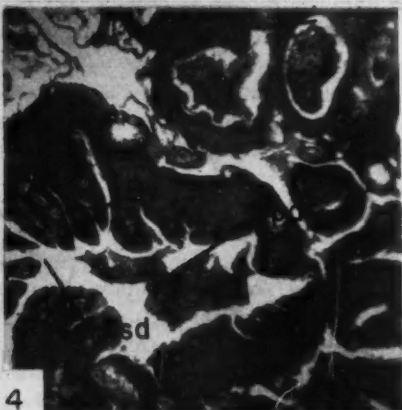
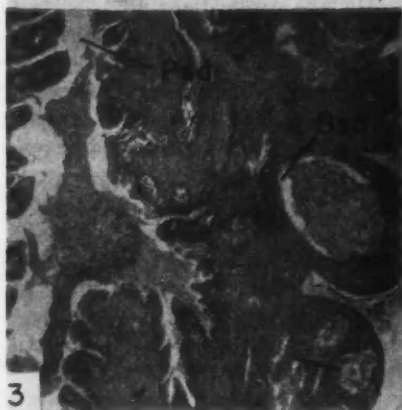
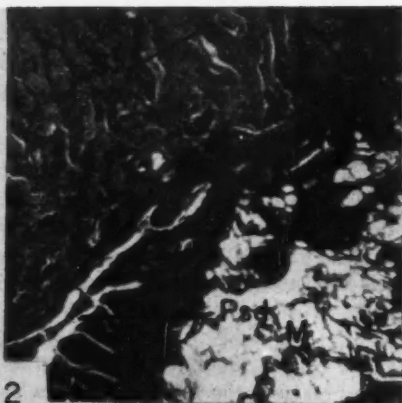
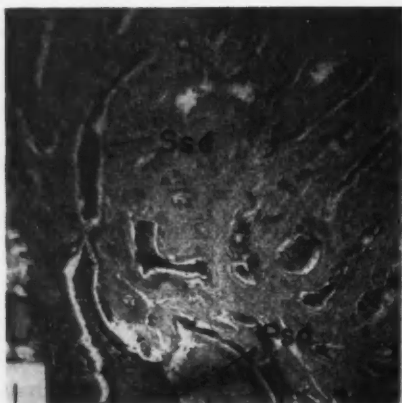
In each specimen examined an antero-posterior gradation in maturity could be observed. In all age-groups mature sperm could be observed.

In age-group IV (62.00 cm., Fig. 5-7) spermatozoa could be seen in the seminiferous tubules only. In the anterior portion of the gonad spermatogonial divisions only were noted.

In age-group V (70.5 cm., Fig. 8) spermatozoa were present in seminiferous tubules, vasa efferentia and vas deferens. In some specimens, however (74.0 cm.), spermatozoa could be found only in the seminiferous tubules.

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²Present address: 104 Union Blvd., Kitchener, Ont.



In age-group VI spermatozoa were found in tubules and ducts in all cases examined (Fig. 9-10).

From these observations it would seem that fish in age-group VI (78.8 cm.) and some individuals in age-group V were in a condition approaching spawning.

THE OVARY

The female gonad is suspended in the body cavity by a mesovarium. It is a hollow structure and its lumen connects directly posteriad to a thick-walled gonoduct, subsequently referred to as an oviduct. Numerous ovigerous lamellae project into the lumen.

As in the testis, development of the gametes shows an antero-posterior gradation.

In all age-groups examined oocytes were present in various stages of development.

In age-group IV (61.0 cm., Fig. 11-15) oocytes varying in size from 2.5μ to 52μ in diameter are conspicuous. These contain some yolk. The nuclei are well marked and contain some basophilic aggregates, possibly nucleoli.

In age-group V (69.1 cm., Fig. 16-17) oocytes showing a size range of 104μ to 180μ were observed. These possessed sheaths of follicular cells and were enveloped in a zona pellucida. The amount of yolk present had increased and the

PLATE I

Figures 1, 2, 3 and 4 are photomicrographs of sections of successive segments from anterior to posterior of a testis from a specimen 70.5 cm. in length (age-group V). Hematoxylin and eosin. Bv, blood vessel; M, mesorchium; Psd, primary spermatid duct; Spa, spermatozoa; Spd, Spermatids; Ssd, secondary spermatid duct; St, seminiferous tubule; V, villus.

FIG. 1 Cross section of a segment showing a vas efferens duct containing spermia (top of figure) opening into the vas deferens. Note vas deferens filled with spermatozoa. Thickness of section, 7μ ; magnification, $100\times$.

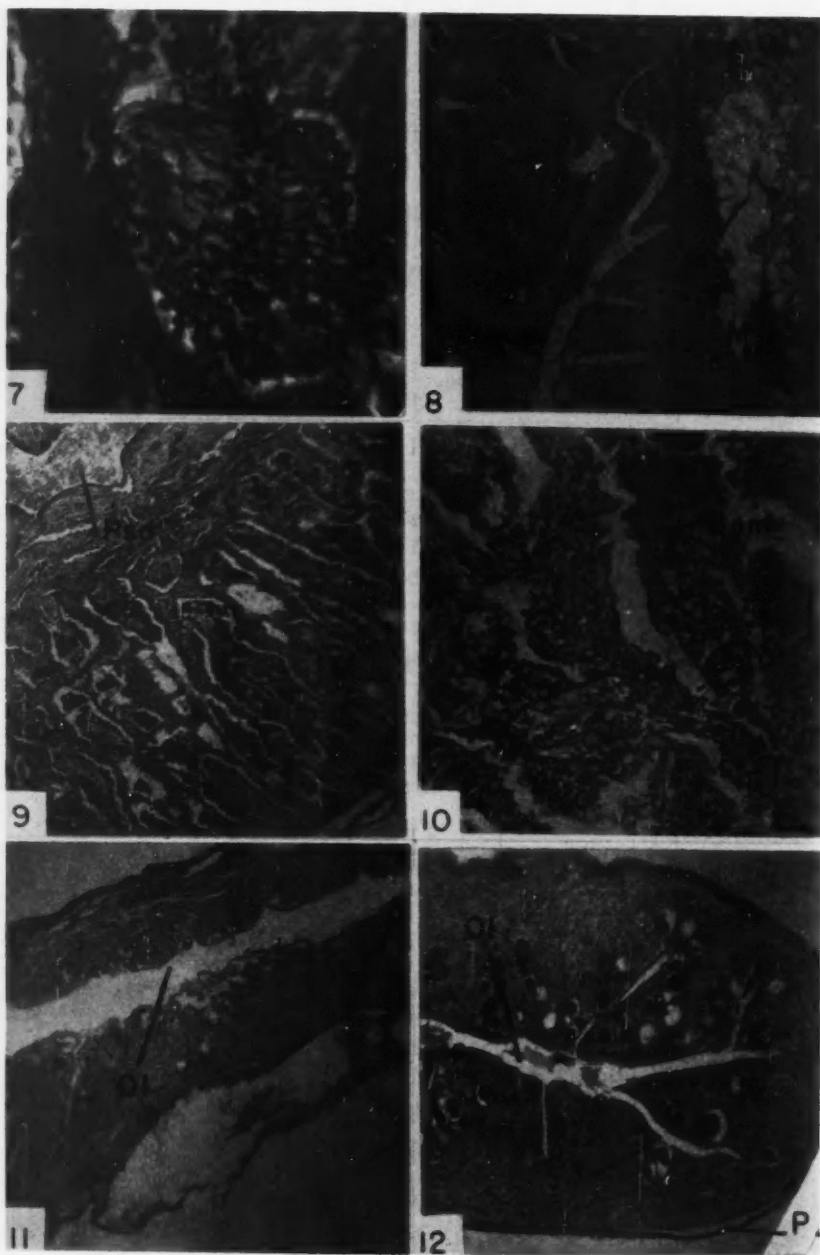
FIG. 2 Cross-section of a segment showing the vas deferens and the attachment of mesorchium to testis. Note germ cells near the testis periphery are in earlier stages of growth and maturation than those more interior, also that the walls of the vas deferens duct are slightly folded. 7μ ; $100\times$.

FIG. 3 Cross-section of a segment showing large secondary sperm ducts near periphery of testis as well as tubules containing spermatogenic cells in latter stages of development. Note folded lining of the vas deferens with numerous blood vessels in each fold. 7μ ; $100\times$.

FIG. 4 Cross-section of the sixth segment (posterior segment) showing oval vas deferens containing many spermia. Note the large vasa efferentia filled with spermia at the top of the figure. 7μ ; $100\times$.

FIG. 5 Cross-section of a mid-segment of a testis from a specimen 62.0 cm. in length (age-group IV) showing numerous tubules containing spermatogenic cells in several stages of development. Note that no sperm are evident in the vas deferens. 8μ ; $100\times$.

FIG. 6 Anterior tip of testis from 70.5 cm. specimen (age-group V) showing mature sperm and spermatids. Note flagella on spermia. 8μ ; $450\times$.



accumulation of vacuoles in the cytoplasm suggested the presence of fat droplets.

In age-group VI (84.9 cm., Fig. 18) the ovary showed a similar degree of development to that of fish in age-group V, but the oocytes, on the basis of cytoplasmic inclusions, appeared to be less mature.

The observations recorded above indicate that, as in the case of the male gonad, fish in age-groups V and VI were in a condition approaching spawning.

DISCUSSION

The histological studies indicate that the British Columbia albacore fishery is dependent on immature fish. No fully ripe gonads nor any atretic follicles were observed.

As noted above, individuals of age-group V are approaching maturity and some of them may be expected to spawn during the current season. Other members of age-group V, however, are less mature and it is believed delay approaching maturity until the following season when they will have entered age-group VI as estimated on the length of the individuals sampled. No individuals of age-groups older than those of group VI were taken and it is believed that individuals do not re-enter the fishery after spawning.

ACKNOWLEDGMENTS

The author is grateful for the assistance of his colleague, Mrs. K. Herlinveaux, in preparing sections, and for the criticism and general help of Dr. P. Ford of the Department of Zoology, University of British Columbia.

PLATE II

Figures 7, 8, 9 and 10 are photomicrographs of sections of testes from several specimens. Hematoxylin and eosin. Bv, blood vessel; M, mesorchium; Psd, primary spermatid duct; Sf, spermatozoa flagella; Spa, spermatozoa; Spm, spermatogonium; St, seminiferous tubule; V, villus.

Figures 11 and 12 are first of a series of 5 photomicrographs of sections from successive parts from anterior to posterior of an ovary of a specimen 61.0 cm. in length (age-group IV). Hematoxylin and eosin. Ol, ovary lumen; Ot, oocyte; P, peritoneum.

FIG. 7 Spermia in a testis section taken from a specimen 62.0 cm. in length (age-group IV). 8 μ ; 1000 \times .

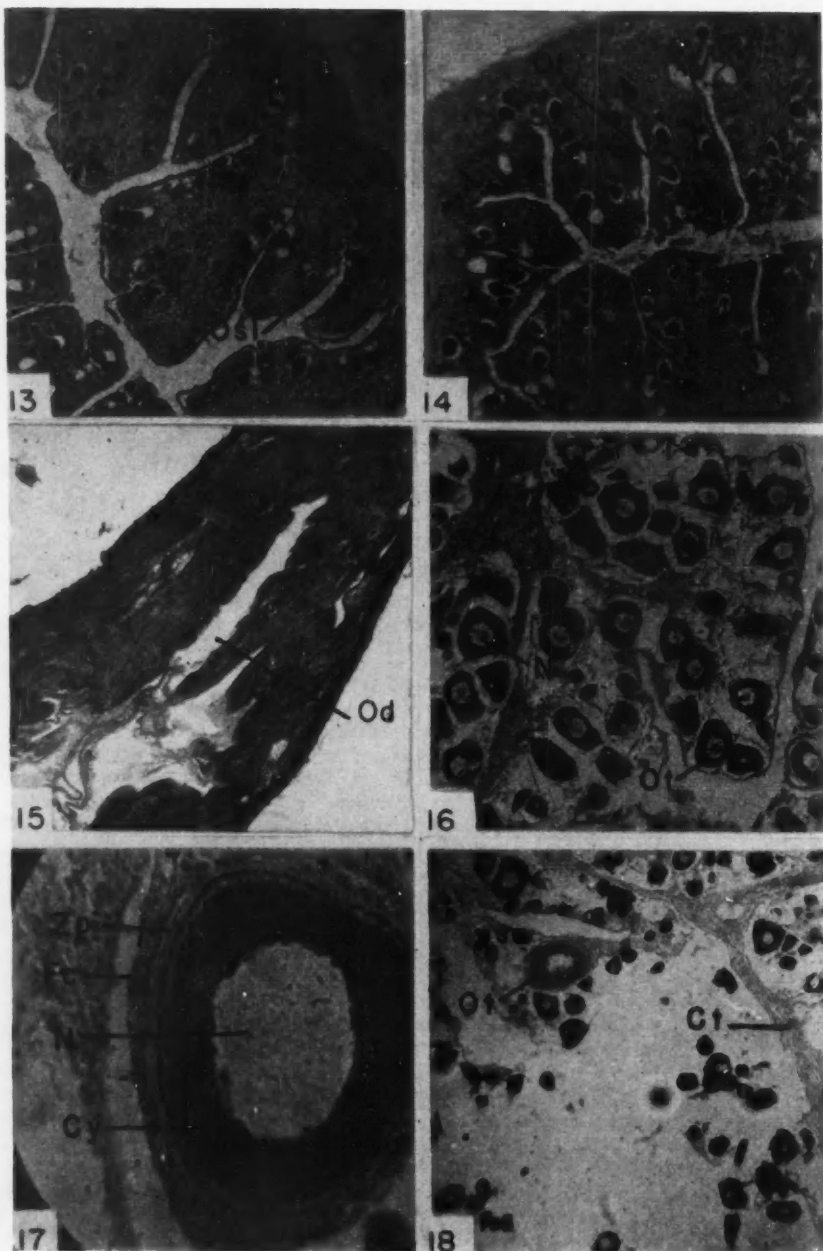
FIG. 8 Cross-section of mid-segment of a testis taken from a specimen 74.0 cm. in length (age-group V) showing tubules containing germ cells in early stages of development. Some tubules contain spermia. 8 μ ; 100 \times .

FIG. 9 Cross-section of mid-segment of a testis from a specimen 78.8 cm. in length (age-group VI) showing many tubules containing spermia, spermatids, and primary germ cells. The vas efferens in the upper left corner of the figure is filled with spermia.

FIG. 10 Higher magnification of section in Figure 9 showing spermatogenic cells in several stages of development. Note groups of spermatozoa with flagella visible. 7 μ ; 450 \times .

FIG. 11 Cross-section of a segment (anterior tip) showing a few ovigerous lamellae and oogonia in early stages of development. 7 μ ; 100 \times .

FIG. 12 Cross-section of a segment. Oocytes in the growing stage are located near periphery of each lamella and the central lumen of the ovary is lined with epithelial cells. The peritoneum covering the ovary is evident. 8 μ ; 100 \times .



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PLATE III

Figures 13, 14 and 15 are photomicrographs of three sections from further successive segments from anterior to posterior of an ovary from a specimen 61.0 cm. in length (age-group IV). Figures 16 and 17 are photomicrographs of mid-ovarian sections from a specimen 69.0 cm. in length (age-group V) captured in August, 1951. Figure 18 is a microphotograph of a mid-ovarian section from a specimen 84.9 cm. in length (age-group VI) captured in September, 1950. Hematoxylin and eosin. Ct, connective tissue; Cy, cytoplasm; Fc, follicle cells; N, nucleus; No, basophilic aggregates; Od, oviduct; Osl, ovigerous lamella; Ot, oocyte; P, peritoneum; Zp, zona pellucida.

- FIG. 13 Cross-section of a segment (medial) showing greater numbers of ovigerous lamellae and a corresponding increase in the number of growing oocytes. 8 μ ; 100 \times .
- FIG. 14 Cross-section of a segment with many ovigerous lamellae and growing oocytes. 7 μ ; 100 \times .
- FIG. 15 Cross-section of a posterior segment shows the oviduct. Surrounding tissue is dense collagen with an outer peritoneal sheath. 8 μ ; 100 \times .
- FIG. 16 Numerous growing oocytes and one oocyte in an advanced stage of growth. Note the decreased thickness of connective tissue surrounding ova and the distinct follicle surrounding the large ovum. 7 μ ; 100 \times .
- FIG. 17 Enlarged section of Figure 16 showing the characteristics of an ovum. Note the oval nucleus with basophilic aggregates. Two layers of follicle cells surround the egg. A zona pellucida may be observed interior from the follicular epithelium. 7 μ ; 400 \times .
- FIG. 18 Thin strands of connective tissue and growing ova of various sizes may be observed. 8 μ ; 100 \times .

The Artificial Drying of Lightly Salted Codfish¹

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ABSTRACT

The mechanical drying of lightly salted fish must be carried out by successive drying periods and press-piling. This procedure considerably reduces the drying time. Best results are obtained at a temperature of 80°F., and at an air velocity of 300 to 400 linear feet per minute. The relative humidity of the drying atmosphere should be maintained at about 50-55 per cent during the first drying period and 60-65 per cent during all subsequent ones. The first drying period should be of sufficient length to reduce the moisture content of the fish to about 55-60 per cent. The operation is then completed by successive 12-hour drying periods. Cross-piling during the press-piling period is important as it gives a product of better quality.

INTRODUCTION

THE sun drying of lightly salted codfish is a long, tedious and laborious method. It depends entirely on atmospheric conditions which are not always favourable.

Cooper and Wood (1940) and Linton and Wood (1945) have investigated the drying of heavily salted fish, with the result that nearly all the heavily salted fish produced on the Canadian Atlantic Coast is now dried in artificial dryers.

The unsuccessful attempts in the past, by some fish processors, to dry lightly salted fish artificially may be explained by the fact that the experiments had been carried out with dryers especially designed for heavily salted fish.

The present investigation, therefore, has been undertaken with the object of finding out what a properly designed dryer has to offer to the lightly salted fish industry. It consists in determining the best conditions which should be used in a dryer to lower the water content of lightly salted fish of the Gaspé Cure type from 300 per cent dry-basis (75 per cent wet-basis) to about 55 per cent dry-basis (36 per cent wet-basis) and produce economically a product of excellent quality.

EXPERIMENTAL

All the experiments were carried out in a small dryer of approximately 250-pound capacity. It was so equipped that any desired air velocity, temperature and relative humidity could be kept constant automatically.

The dryer was always filled to capacity with fish of the same size which had been salted previously either at this station or at commercial fish plants.

The average moisture (water) content of the fish was 75 per cent wet-basis or 300 per cent dry-basis. Its salt content was 4 per cent wet-basis or 16 per cent dry-basis.

The loss in weight due to the evaporation of moisture from the fish was followed by weighing samples from several racks at intervals.

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All moisture contents are given on the dry basis; that is, pounds of water per 100 pounds of dry material. On that basis, the percentage change in moisture is constant for all moisture contents. The moisture loss may thus be obtained directly by subtracting the moisture contents before and after drying.

The data recorded in this investigation represent the loss of moisture by the fish. As such, a better comparison is obtained between experiments because the starting point is always the same whatever the initial moisture content of the fish. It is also possible by this means to obtain the drying rate directly by a simple graphical differentiation of the moisture loss curve.

TEMPERATURE

Several experiments were carried out at temperatures ranging from 65° to 85° F., both relative humidity and air velocity remaining constant at 55 per cent and 300 linear feet per minute, respectively. The relative humidity and air velocity were not chosen at random. Several initial experiments had been carried out to find a range within which these experiments could have been carried out with a reasonable assurance of being able to ascertain the effect of temperature on drying and on the quality of the dried product. Figure 1 shows the effect of temperature on the drying rate for about twenty-five hours. It shows, as could have been expected, that the rate of water evaporation increased with temperature. At 65° F., it took 31 hours to evaporate 100 pounds of water per 100 pounds

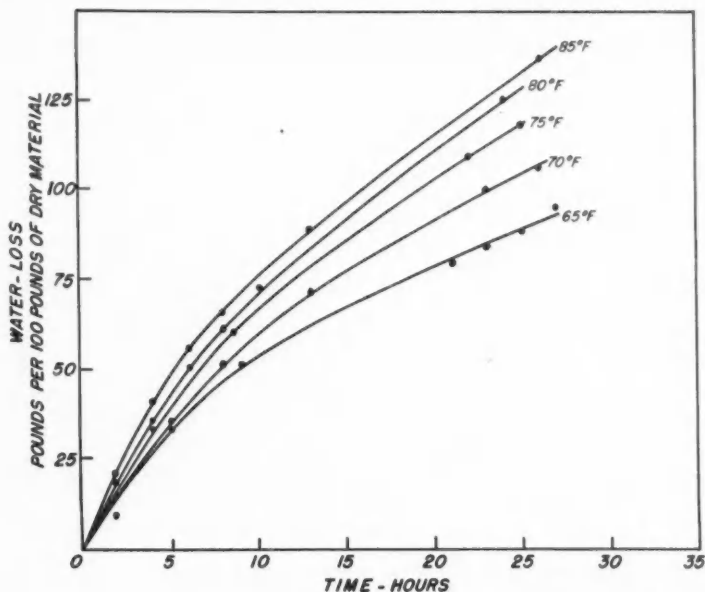


FIGURE 1. Water-loss curves showing the influence of temperature on the drying rate. Relative humidity 55%. Air velocity 300 feet per minute.

of dry material; whereas at 85° F., it took 15 hours to evaporate the same amount.

It was impossible to show graphically the cooking effect of high temperatures, but observations showed that 80° F. is about the highest temperature to which lightly salted fish can be subjected without damage. At higher temperatures, in the early drying, so much water is evaporated that the surface of the fish cools down to a level closely corresponding to the wet bulb temperature. However as the drying proceeds, the surface dries up and tends to reach the dry bulb temperature, a danger point which, in the vicinity of 85° F. is characterized by a cracked and yellow surface.

Furthermore, there is no point in drying the fish at low temperatures, because, as it is always desirable to operate at the highest safe temperature, it becomes obvious that for all practical purposes, lightly salted fish of the Gaspé Cure type should be dried at approximately 80° F.

AIR VELOCITY

It is a universally known principle that a high air velocity results in more rapid drying, more even distribution of temperature and consequently more uniform drying during the initial drying period. Because excessive air velocities are costly, experiments were carried out at different air velocities, at a temperature of 80° F., and relative humidity of 55 per cent, to determine the minimum permissible air velocity at which drying operations could be carried out to obtain a product of good quality.

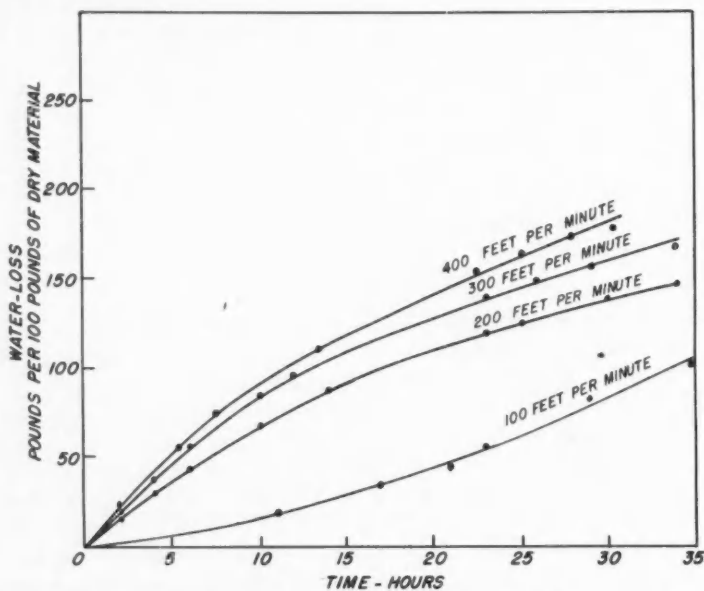


FIGURE 2. Water-loss curves showing the influence of air velocity on the drying rate. Relative humidity 55%. Temperature 80°F.

Figure 2 illustrates the effect of air velocities on the drying rate. At 100 feet per minute drying is too slow, the surface of the fish remains wet, and since the temperature of the dryer is quite favourable to bacterial development, sliming takes place. Therefore the initial drying should be carried out at such a rate as to hasten the formation of a thin dry film at the surface of the fish. An air velocity of 200 feet per minute seems to fulfil the minimum conditions which are necessary to meet these requirements. Yet under these conditions the formation of the required surface dryness is too slow. Even at 250 feet per minute and at low relative humidities, sliming is apt to take place. The most satisfactory results are obtainable at air velocities of 300 to 400 feet per minute.

RELATIVE HUMIDITY

Drying as affected by relative humidity is shown in Figure 3. The curves represent the water loss at relative humidities ranging from 50 to 65 per cent, with temperature and air velocity constant at 80° F. and 300 linear feet per minute, respectively. After 20 to 25 hours the surface became dry, and the fish was press-piled for 24 hours then submitted to further drying. This procedure of successive press-piling and drying was repeated several times.

The curves indicate that relative humidity governs the drying rate during the initial drying period and also at the early part only of each following period. In other words, relative humidity influences the drying rate as long as the surface of the fish is still wet. Therefore, once the surface is dry, the drying rate

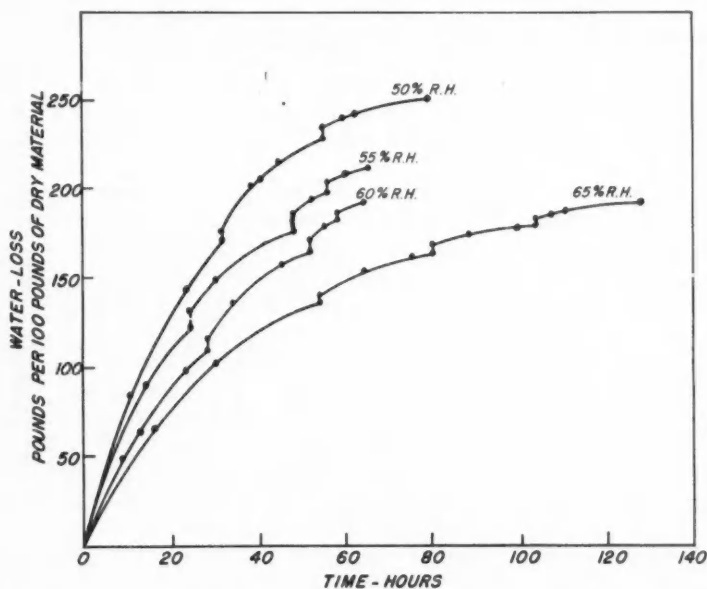


FIGURE 3 Water-loss curves showing the influence of relative humidity on the drying rate. Temperature 80°F. Air velocity 300 feet per minute.

depends chiefly on the mechanism which governs the diffusion of moisture from within the fish to the surface. However, during the second drying periods, the fish submitted to 50 and 55 per cent relative humidities showed surface cracking, a condition which could not be observed at 60 and 65 per cent relative humidities. It seems therefore that the small amount of moisture which has diffused to the surface of the fish during press-piling should be evaporated at a rate as close as possible to that of the diffusion of moisture from within to the surface of the fish. The relative humidities of 60 and 65 per cent seem to fulfil this requirement. Higher relative humidities promote sliming.

DRYING

Experiments have shown that the time required for drying lightly salted fish is considerably reduced by successive drying and press-piling operations.

Two sets of experiments were carried out on fish of approximately the same size, 18 to 22 inches in length, at a temperature of 80° F. and an air velocity of 300 feet per minute.

The results of the first experiment (Fig. 4) show the water-loss and the drying rate curves of a continuous drying operation at 55 per cent relative humidity. Those of the second experiment show the water-loss and the drying rate curves of a drying operation interrupted by successive drying and cross-piling periods.

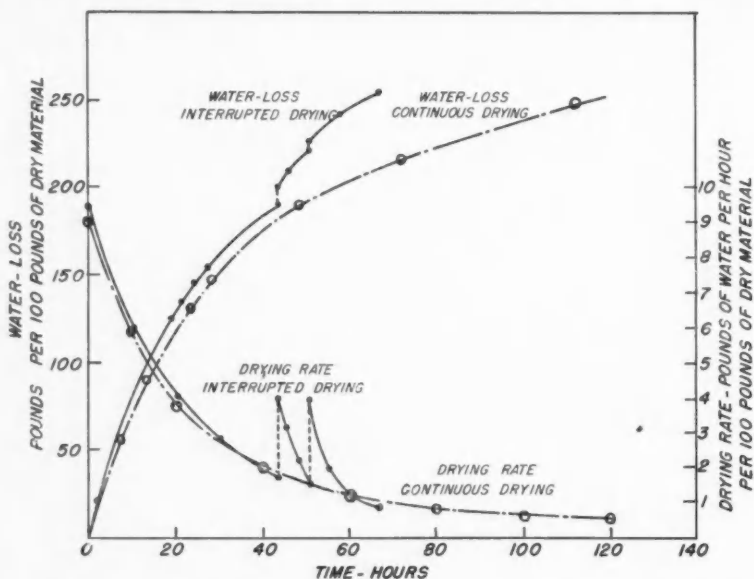


FIGURE 4. Water-loss and drying rate curves: *Continuous drying*—temperature 80° F., air velocity 300 feet per minute and relative humidity 55 per cent. *Interrupted drying*—temperature 80° F., air velocity 300 feet per minute and relative humidity 55 per cent for the first drying period and 60–65 per cent for the succeeding ones.

The first period was carried out at 55 per cent relative humidity and the succeeding ones at 60-65 per cent relative humidity. It took 120 drying hours to remove 250 pounds of moisture per 100 pounds of dry material in the first experiment, and 63 drying hours to remove the same amount of moisture in the second.

In the case of one single continuous drying operation the drying rate decreases continuously because of case-hardening which retards the flow of water from the inside to the surface of the fish. On the other hand, in the case of interrupted drying immediately followed by press-piling, the drying rate is much higher at the initial stage of any one period than at the final stage of the preceding one. For instance, on the basis of 100 pounds of dry material the drying rate at the end of the first period was about 1.5 pounds of water per hour whereas at the beginning of the second period the rate was 4 pounds per hour.

The increased rate at the beginning of these periods can be explained by the fact that water, which is subsequently easily evaporated, diffuses from the inside to the surface during press-piling. Some of this water is obviously lost during the actual press-piling as is evident by sudden jumps on the water-loss curve.

It may be argued in general that the overall time consumed for drying lightly salted fish of the Gaspé Cure type is the same whether it is dried in one continuous drying operation or not, but this is not so in practice. By alternating drying and press-piling periods the actual drying operation, exclusive of the time consumed for press-piling, is considerably shorter; therefore the dryer operates at a more efficient level than it would under conditions of continuous drying. Also, the quality of the fish is one important consideration which must not be overlooked. Continuous drying cannot result in a product of uniform water distribution. The surface, and the flesh to some perceptible depth, are altogether too dry before the total required removal of water content of the fish is realized. Consequently the surface cracks and too much salt crystallizes out to give the product an acceptable appearance.

With a similar object in mind the drying periods preceding each press-piling should not be too long. If the surface is too dry the diffusion of water from the inside to the surface will be that much slower and no time will be gained by such operations. On the other hand if the drying period is not sufficiently long and the surface is not sufficiently dry there will be grave danger of sliming during the subsequent press-piling period.

Experiments have shown that best results are obtained by interrupting the first drying period when the water content of the fish has reached 55 per cent wet-basis or 122 per cent dry-basis. The loss in weight during this period is approximately 45 per cent of the original weight of the fish. At a temperature of 80° F., a relative humidity of 50 per cent and an air velocity of about 400 linear feet per minute, the length of the first drying period should be about 30 to 35 hours depending upon the size of the fish. The length of the subsequent drying periods will also depend upon the size of the fish and the press-piling conditions. As a general rule these should not last much longer than 12 hours at 60 to 65 per cent relative humidity.

PRESS-PILING

The purpose of press-piling is to permit an even distribution of water inside the fish by promoting the internal diffusion of water to the surface. Therefore it is necessary to remove the fish from the dryer and press-pile it.

The relative humidity must be high enough so that surface drying will be reduced to a minimum. However, it is very important that no condensation occur from the air to the surface of the fish, and for that reason relative humidities higher than 70 per cent are to be avoided. A relative humidity of about 65 per cent is recommended.

The temperature must be about 55–60° F. Lower temperatures retard the diffusion rate and higher temperatures promote bacterial development.

The duration of press-piling depends on several factors, such as water content of the fish, water distribution in the fish, size of the fish, size of the pile, atmospheric conditions. As a general rule, it may be said that the press-piling has been of sufficient duration when the surface of the fish has become wet. Since the diffusion rate is increased by pressure, the surface of the fish becomes moist much more rapidly at the bottom than at the top of the pile. Therefore to equalize the diffusion process it is necessary to re-pile the fish from time to time. Moreover, this re-piling process promotes the formation of a thin layer of salt at the surface and greatly enhances the final appearance of the fish. Experiments have shown that a press-piling period of 24 hours with several re-pilings between the first and second drying period is sufficient. Then the duration of the second press-piling will be about 4 to 6 days and that of the third 8 to 10 days. Re-piling every two days is of great benefit.

SUMMARY

1. To obtain good results, the drying operation must be conducted in several successive drying periods.
2. The drying rate increases with temperature. A temperature of 80° F. is about the highest at which the fish will not be damaged.
3. An air velocity of 300 to 400 linear feet per minute must be maintained in the dryer.
4. Relative humidity influences the drying rate chiefly during the first drying period, but the relative humidity is important to the quality of the product during the last periods. Best results are obtained by using a low relative humidity (50–55 per cent) for the first drying period and a higher relative humidity (60–65 per cent) for the following periods.
5. The first period of drying must be carried on until the water content of the fish has reached about 55 per cent wet-basis or until the fish has lost about 45 per cent of its original weight. The operation is then completed in successive drying periods of 12 hours. Press-piling and re-piling the fish between drying periods is important and contributes to better quality.

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Electrophoretic Studies of Proteins Extractable from Post-Rigor Cod at Low Ionic Strength^{1,2}

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ABSTRACT

Extracts of post-rigor cod muscle made at low ionic strength have been examined by electrophoresis in sodium chloride phosphate buffers of ionic strength 0.15 ($\text{NaCl} = 0.10$) and pH between 5.3 and 7.5. The patterns were qualitatively similar to those reported for extracts made from freshly killed cod. At the lower pH values, ten components could be distinguished. The highest isoelectric point found was at pH 5.9, much lower than those reported for similar proteins from rabbit.

INTRODUCTION

IN recent years attention has been given to the study of muscle proteins by electrophoresis, but very little has been devoted to those derived from fish. Reviews on the proteins of fish have been published by Geiger (1948) and by Hamoir (1951b). Hamoir (1949, 1951b) has compared the electrophoresis patterns of extracts of carp muscle with those from rabbit muscle, and has also studied tropomyosin, nucleotropomyosin, and myoglobin prepared from carp muscle (1951a, c; 1953). Henrotte (1952) has described a crystalline constituent from the myogen fraction of carp muscle. The only reported electrophoretic studies on proteins from fishes of commercial importance are contained in two recent papers by Connell (1953a,b). In the first, mobilities and relative concentrations of the various components were determined from the electrophoretic patterns of extracts of codling muscle at ionic strengths 0.05, 0.10, and 0.15, and pH 7.3 to 7.6. In the second study, extracts from the muscles of 20 different species of fish were compared at ionic strength 0.05 and pH 7.5. In Connell's work, all the extracts were made from minced muscle obtained from freshly killed specimens.

In this laboratory, we have been interested in the changes that occur in post-rigor commercial frozen fish during storage. As a part of our program, an electrophoretic study has been made of the proteins extracted from post-rigor cod muscle by salt solutions of low ionic strength.

EXPERIMENTAL

Commercial fillets cut from cod having a length of 80 to 100 cm. were used. Post-mortem storage time in ice aboard the trawlers was uncertain, but probably varied from two to six days. Those fish used in the later runs, however, were caught inshore, and had been kept in ice for not more than eight hours. All the

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²Paper No. 5 of a series "Proteins in fish muscle".

cod used, with one exception, had passed through rigor mortis. The preparative operations were carried out in a cold laboratory at 1° to 2° C., using precooled materials.

In the earlier experiments, 100 g. of cod fillet was homogenized in a Waring blender with 350 ml. of 0.1 M-sodium chloride solution for about one minute. The vortex was eliminated by use of a baffle plate loosely fitting in the blender jar below the surface of the solution (Dyer *et al.*, 1950). In every case the extract, after centrifuging at $680 \times g$., was very turbid. In the electrophoretic patterns, the turbidity was found to be associated with a prominent peak, the relative size of which varied from extract to extract. This material was not found by Connell in his extracts made from pre-rigor cod, and further evidence indicated that it probably consisted of aggregated "disordered" protein. For example, after centrifuging for 30 minutes at $14,000 \times g$., one such extract yielded a clear supernatant, and the electrophoretic pattern of this lacked the turbid peak. This indicated a molecular weight of at least 30 million for the material causing the cloudiness, well beyond the usual molecular weights of soluble proteins.

It was found that a small amount of air sometimes leaked into the blender jar through the bearing. This leak was overcome by fitting the jar with a screw cap, having a housing for the baffle handle, and admitting compressed air at 2 cm. of mercury. The extracts obtained with this apparatus were still cloudy, and it is possible that denaturation of protein occurred at the surfaces of minute air bubbles that would be expected to form by cavitation near the blades. It is also possible that protein was coagulated by copper or zinc derived from the brass bearing of the blender; these proteins have been found to be precipitated by small amounts of these ions.

In view of the difficulties arising from the presence of the turbid material in the Waring blender extracts, later preparations were made by mixing unbuffered water or 0.1 M-sodium chloride with an equal weight of cod muscle minced in an ordinary food chopper and allowing the mixture to stand unstirred overnight. After centrifuging at $680 \times g$., such extracts were found to be only moderately opalescent; when mechanical stirring was used, however, the turbidity of the extracts was considerably greater. The minced fish extracts were found to contain 0.44 ± 0.08 g. protein nitrogen per 100 g. of muscle used; 0.1 M-sodium chloride extracted slightly more protein than did water. The amount of protein extracted also depended on the condition of the fish.

After centrifuging the crude extracts, aliquots were dialysed for electrophoresis in Visking cellulose tubing against sodium chloride phosphate solutions of total ionic strength 0.15 ($\text{NaCl} = 0.10$ M). Three changes of buffer were used; the volume of buffer in the first two changes was always at least ten times that of the protein solution, while in the final change the ratio was not less than 20:1. The time of dialysis for each change was at least eight hours. Stirring of the dialysing solution with a magnetic stirrer sometimes caused a temperature rise of as much as 10°C.; the use of a slowly driven conventional stainless steel stirring rod was found to be more satisfactory.

Nitrogen analyses on the dialysed extracts were usually carried out by a micro-Kjeldahl procedure (Dyer *et al.*, 1950). When, however, the samples were clear or only moderately opalescent, the more rapid biuret procedure of Snow (1950) was used. The turbid material always found in the extracts made with the Waring blender interfered with the latter method, because an opalescence persisted in the biuret solution.

Electrophoresis was carried out in a Klett Tiselius apparatus at 0.8°C. with the analytical cell. Photographic records were made, using the Longworth schlieren scanning technique, with nearly monochromatic light of $\lambda = 580 \text{ m}\mu$. The dialysed samples were centrifuged at $750 \times g$. for 15 to 20 minutes before filling the cell. The amount of precipitated protein was usually very small provided the final pH was greater than 6.3. The final dialysing solution was used to complete the filling of the apparatus.

RESULTS

In the following text and figures, the numbering of the peaks in the electrophoresis patterns corresponds to that used by Connell (1953a), with peak number one having the highest mobility.

A few typical patterns found for extracts made with the Waring blender are reproduced in Figures 1 to 4. At pH values above about 6.1, such patterns always showed a prominent turbid peak (c), and the turbidity was frequently such that the slower peaks were obliterated in the ascending limb. For this reason, only the patterns from the descending limb are shown. In addition to the peaks shown, there was a small, rapidly-moving peak (1) visible in the ascending patterns after short times of electrophoresis.

The presence of the turbid peak (c) distinguished these extracts from those of Connell, which were made from minced pre-rigor cod without the use of the Waring blender. In one experiment, a portion of a fillet from a freshly caught cod was extracted just as rigor mortis was setting in. The remainder of the fillet was stored at 1°C. for one week in an airtight bag, and then a similar extraction was made. The patterns obtained from these extracts are shown in Figures 1a and 1b. They both contained a large amount of the turbid material, unlike the extracts of pre-rigor cod made by Connell.

Figures 2a and 2b show the patterns obtained from extracts of samples of the same post-rigor fillet made one week apart. The fillet was stored in an airtight bag at 1°C. There was a slight, but hardly significant decrease in the mobilities of all the peaks except (c) in the extract from the aged fillet. The mobility of (c), on the other hand, had increased slightly.

Aliquots of an extract of post-rigor cod were dialysed against sodium chloride solutions buffered to several pH values, and the patterns from those run at pH 6.38 and 6.03 are shown in Figures 3a and 3b. As the pH was decreased, the solutions became progressively cloudier, until at pH 6.03, considerable precipitation had occurred, and the supernate was clear. This change was associated with a total loss of the turbid peak (c). The pattern (Fig. 3b) now resembled closely those obtained by Connell from extracts of minced pre-rigor cod, except

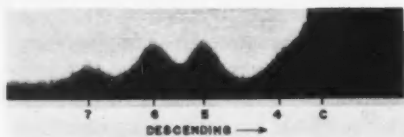


FIGURE 1a. Electrophoresis pattern of cod proteins extracted with a Waring blender at beginning of rigor.

$\mu = 0.15$; pH = 6.52; 4.42 volt/cm.; 25,440 sec.

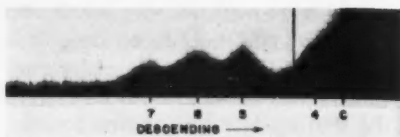


FIGURE 1b. Electrophoresis pattern of cod proteins extracted with a Waring blender after rigor.

$\mu = 0.15$; pH = 6.59; 4.66 volt/cm.; 21,960 sec.

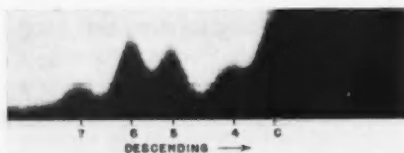


FIGURE 2a. Electrophoresis pattern of proteins extracted with a Waring blender from post-rigor cod.

$\mu = 0.15$; pH = 6.73; 4.95 volt/cm.; 18,180 sec.

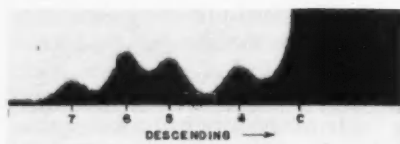


FIGURE 2b. Electrophoresis pattern of proteins extracted with a Waring blender from same fish after storage for one week at 1°C.

$\mu = 0.15$; pH = 6.58; 5.02 volt/cm.; 18,960 sec.

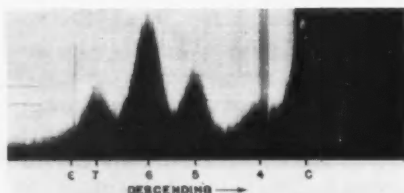


FIGURE 3a. Electrophoresis pattern of proteins extracted with a Waring blender from post-rigor cod.

$\mu = 0.15$; pH = 6.38; 4.68 volt/cm.; 1.43 mgN/ml.; 19,080 sec.

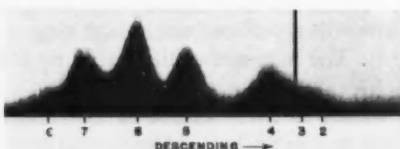


FIGURE 3b. Electrophoresis pattern of same extract as in Figure 3a.

$\mu = 0.15$; pH = 6.03; 4.33 volt/cm.; 0.961 mgN/ml.; 18,540 sec.

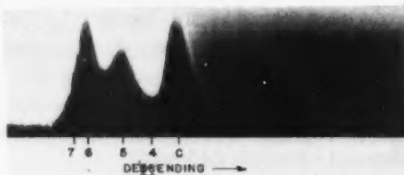


FIGURE 4. Electrophoresis pattern of proteins extracted with a Waring blender from post-rigor cod.

$\mu = 0.15$; pH = 7.40; 4.52 volt/cm.; 1.01 mgN/ml.; 11,200 sec.

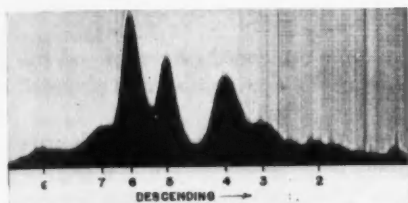


FIGURE 5a. Electrophoresis pattern of proteins extracted from minced post-rigor cod.
 $\mu = 0.15$; pH = 6.50; 8.77 volt/cm.; 2.88 mgN/ml.; 14,400 sec.

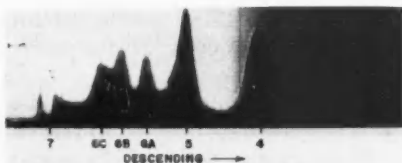


FIGURE 5b. Same extract as in Figure 5a.
 $\mu = 0.15$; pH = 5.82; 8.80 volt/cm.; 2.30 mgN/ml.; 14,340 sec.

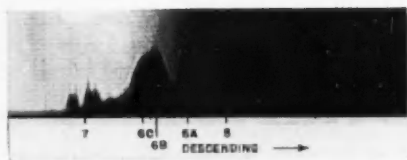


FIGURE 5c. Same extract as in Figure 5a.
 $\mu = 0.15$; pH = 5.74; 8.70 volt/cm.; 2.22 mgN/ml.; 14,400 sec.

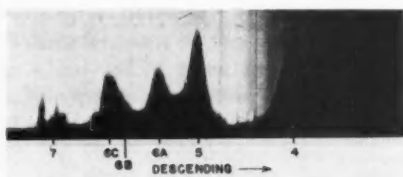


FIGURE 5d. Same extract as in Figure 5a.
 $\mu = 0.15$; pH = 5.62; 8.97 volt/cm.; 2.06 mgN/ml.; 15,060 sec.

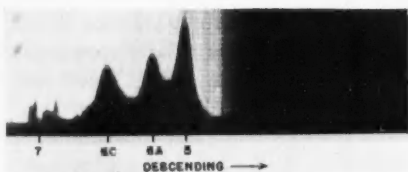


FIGURE 5e. Same extract as in Figure 5a.
 $\mu = 0.15$; pH = 5.53; 8.85 volt/cm.; 2.20 mgN/ml.; 14,400 sec.

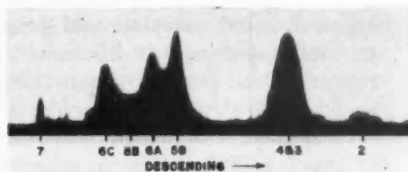


FIGURE 5f. Same extract as in Figure 5a.
 $\mu = 0.15$; pH = 5.40; 8.90 volt/cm.; 2.10 mgN/ml.; 14,640 sec.

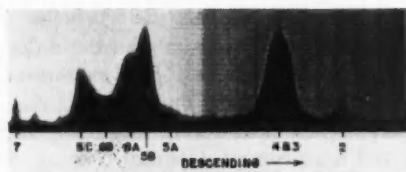


FIGURE 5g. Same extract as in Figure 5a.
 $\mu = 0.15$; pH = 5.26; 9.01 volt/cm.; 2.02 mgN/ml.; 15,320 sec.

for the better resolution of the slower components obtained at the lower pH used here.

In Figure 4 is shown the pattern obtained from a blended extract of cod run at pH 7.40. This illustrates the poorer resolution of the slow components obtained at higher pH.

In Figure 5 are reproduced electrophoresis patterns obtained from aliquots of a single extract dialysed to various pH values at an ionic strength of 0.15. The starting solution was made by extracting 750 g. of minced cod fillet with 500 ml. of water for four hours without stirring. The turbid material always found in extracts made with the Waring blender was absent, and the electrophoresis patterns resembled those obtained by Connell for pre-rigor cod. As the pH was lowered, some of the protein precipitated; the precipitate could not be re-dissolved in 0.1 M-sodium chloride buffered at pH 6.5. In some cases, particularly around pH 5.7, the solution became very turbid, and the material responsible for this could not be removed even by centrifuging at $20,000 \times g$. From a comparison of the areas of the peaks at various pH values, it appeared that the precipitated protein consisted of those components represented by the group of peaks 5 to 7, while components 3 and 4 were practically unaffected. At pH 5.8, peak 6, which apparently represented a monodisperse component at higher pH values, had separated into three distinct peaks. In another sample of cod extract, run for a longer time, peak 5 also separated into two, and probably a third, minor peak. The most rapid peak had left the field by the time the photographs were made. The multiple peaks in the slowest position were artifacts probably caused by convection disturbances set up by the rather high current densities employed in these runs. At lower currents, they appeared as a single peak, but then the resolution of the main peaks was less distinct because of the increased importance of diffusion. There thus appears to be at least ten components in the protein mixture extractable from post-rigor cod at low ionic strengths.

The areas of the peaks in the patterns of a number of similar extracts made for various purposes were measured by planimeter, after drawing approximate Gaussian curves under the peaks. The reproducibility was not found to be satisfactory, probably because of several of the following: (a) the arbitrary nature of the Gaussian curves, (b) frequent difficulty in establishing a good base line, (c) the possibility of denaturation having occurred during preparation, (d) the varying condition of the fish before extraction, and (e) uncertainty in allowances to be made for the δ and ϵ boundaries, particularly at the lower pH values. The base line was particularly difficult to settle whenever any turbid component was present. Table I, however, will serve to give the order of magnitude of the relative areas of the peaks, as found for a typical pattern at pH 6.57.

The mobilities were calculated in most cases from measurements made directly from the plates. When peaks were close together, however, enlarged tracings were made, and approximate Gaussian curves drawn in an effort to locate the individual peaks more accurately. The ascending mobilities were always greater than the descending ones, but no corrections were applied. The

TABLE I. Composition of extract of minced cod (from electrophoresis pattern at $\mu = 0.15$; pH = 6.57).

Peak	Percentage of total area		Composition of pre-rigor codling ^a (Connell, 1952)
	Rising	Descending	
1	1.4	1.3	3.5
sp	—	—	5.9
2	2.9	3.0	7.6
3	14.2	13.2	6.9
4	12.4	15.3	9.5
5a	1.8	2.4	—
5b, c	19.9	17.9	25.4
6a, b, c	36.1	34.8	30.2
7	11.2	12.2	11.4

^aElectrophoresis patterns made at $\mu = 0.05$ and pH 7.5

descending mobilities obtained from all of the reliable runs so far made are plotted in Figure 6. Some of the points plotted for peaks 1 and 2, however, are ascending mobilities, because the presence of the cloudy component frequently obliterated these in the descending patterns. The graph contains data from extracts made by both procedures, using many different samples of commercial cod fillets. The points plotted at pH 6.52 represent means of many runs near this pH, and are given separately in Table II.

DISCUSSION

When cod muscle is extracted in the Waring blender with 5 per cent sodium chloride solution at pH 7 to 8, up to 95 per cent of the total protein present can be brought into solution (Dyer, French and Snow, 1950). When such a solution is diluted to less than 1 per cent sodium chloride, approximately 70 to 80 per cent of the protein precipitates (actomyosin); that remaining in solution was supposed to be myogen, globulin-X, and myoalbumin. Dyer (1953) found for 123 samples studied, that the nitrogen contained in these "easily soluble" proteins was 0.47 ± 0.067 g. per 100 g. of muscle extracted. The agreement between

TABLE II. Average mobilities of components of extracts of post-rigor cod at pH 6.5, ionic strength 0.15, and temperature 0.8°C.

	Component						
	1	2	3	4	5	6	7
Arithmetic means of mobilities in $cm^2 \text{ volt}^{-1} \text{ sec}^{-1}$	8.4	4.47	3.66	3.02	2.17	1.55	0.82
Standard deviation $\left[\sqrt{d^2/(n-1)} \right]$	0.3	0.25	0.14	0.10	0.09	0.11	0.10

this value and that obtained in the present work, suggested that the extraction of these proteins from minced muscle was nearly quantitative. Moreover, the ease of the extraction makes it seem unlikely that these proteins are bound to the actomyosin proteins in the intact muscle.

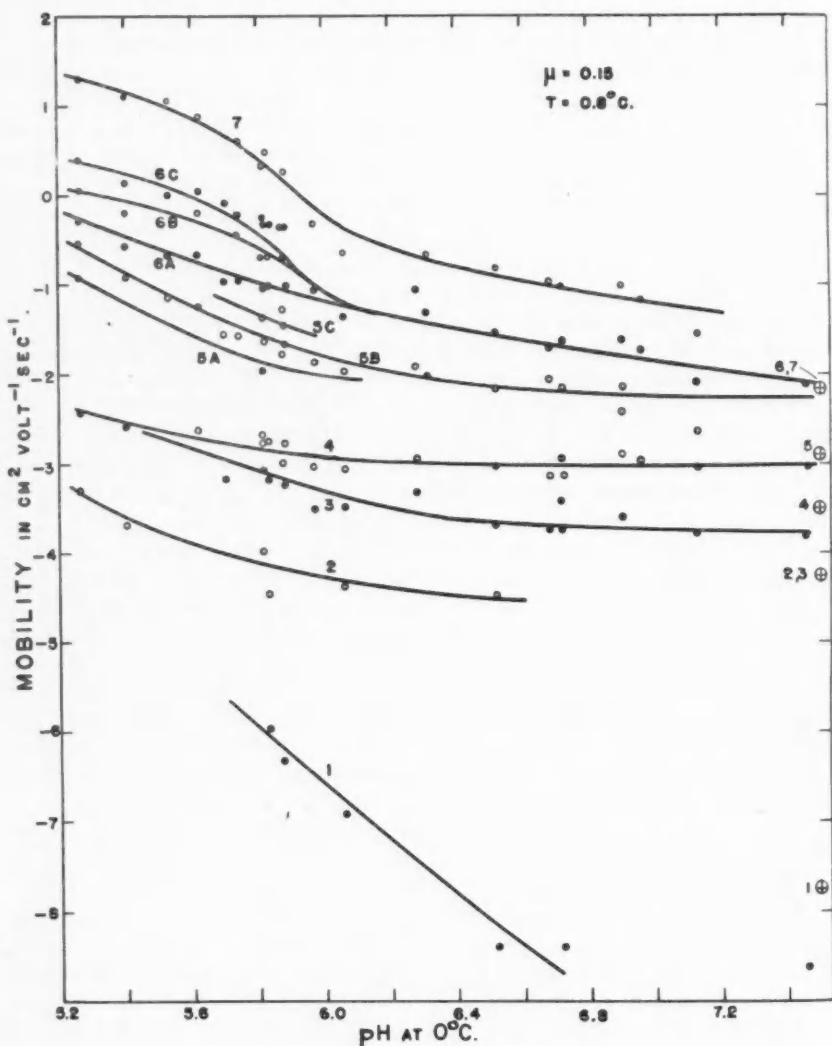


FIGURE 6. Electrophoretic mobilities of proteins extracted from post-rigor cod at low ionic strength. Points shown as \oplus are from Connell (1953a), interpolated for ionic strength 0.15.

By comparing the present results with those of Connell, it is seen that the mobilities of the corresponding components in extracts from pre-rigor cod and from post-rigor cod agree fairly well at pH 7.5. The electrophoretic patterns of the extracts are qualitatively similar. In the post-rigor extracts, however, there appears to be a smaller proportion of component 5, and a larger proportion of components 3 and 4. This recalls an observation of Haan (1953) who noted that for rabbit muscle, rigor mortis entailed a distinct increase in component 4 and possibly an increase in the region between components 1 and 2. The significance of this change, however, is not known.

It happens that the electrophoretic patterns of extracts made from rabbit muscle at low ionic strength resemble those made from cod (Haan, 1953; Jacob, 1947). It is found, however, that the mobilities of the components in cod extracts, are higher than those of the apparently corresponding ones from rabbit. Hence, the slowest component of the cod proteins has an I.P. of about pH 5.9, while the corresponding rabbit protein has an I.P. of 6.8 according to Jacob. From the literature, this difference between the proteins of fishes and of higher vertebrates appears to be general. Haan (1953) also observed that the slowest component of the rabbit proteins subdivided into two or three peaks between pH 6.4 and 6.0. This recalls the splitting of the second slowest cod peak at low pH values. The wide variation of electrophoretic patterns found by Connell (1953b) even for extracts from many species of fishes, however, urges caution in the comparison of such extracts.

The present work is yet another illustration of the desirability of using a considerable pH range in the electrophoretic study of proteins. Of the ten components found, several would have been missed if the pH had not been decreased below 6. Moreover, the better separation obtained at the lower values was of considerable assistance in estimating the relative amounts of the components.

No attempt has been made to assign the old names, myogen, globulin-X and myoalbumin, to the peaks found in the electrophoretic patterns of cod, since these almost certainly refer to mixtures of proteins (see, for example, Connell, 1953a). Myogen, however, appears to be composed chiefly of the slow-moving components 5 to 7 in analagous rabbit muscle extracts while myoalbumin is thought by the Dubuissou school to be represented by the most rapid component. The "easily soluble" proteins are known to be associated with certain enzyme activities. Distèche (1953) has isolated from rabbit muscle fractions that show aldolase and glycerophosphate dehydrogenase activity, and Petrova (1949) has described a fraction having amylose isomerase activity. Work is in progress at this laboratory with a view to isolating the components of the cod extracts as fairly pure fractions, and then studying their enzymic properties.

ACKNOWLEDGMENT

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Economic Factors in Catch Fluctuations^{1, 2}

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ABSTRACT

Correlation methods were employed in a statistical analysis of the relation between catch fluctuations and economic factors for the principal Canadian commercial species of the Atlantic and Pacific coasts. The results indicate that the major part of catch fluctuations are ascribable to economic factors in the cases of Atlantic herring, "sardines", and cod (tentative), and Pacific herring. Economic factors appear to have had no significant effect on the catches of Atlantic lobsters and Pacific halibut and salmon.

INTRODUCTION

IN AN EARLIER paper in this journal [1], the writer advanced the proposition that the proper objective of fisheries management policy is the achievement of an intensity of exploitation defined in terms of an *economic* optimum. A theoretical analysis was employed in order to demonstrate that, in the absence of management, powerful factors are steadily at work which result in the dissipation of the economic benefits of the fishery. In another paper [2], an effort was made to construct a simple algebraic model of the fishery containing both economic and biological factors which would indicate what information must be obtained and what conditions must be satisfied in order to achieve the economically optimum level of exploitation.

This algebraic model can hardly be described as a "practical" one at the present time, requiring, as it does, estimates of the absolute size of the species population under natural conditions and a "depletion coefficient" that measures the reduction in the population brought about by different catch levels. However, it is evident that, in order to make any approach to the determination of the optimum level of exploitation, more empirical knowledge must be obtained concerning the "fisheries production function"—the relationship between the catch of a species and the various factors (both economic and "natural") that are responsible for its variations. In the present paper, an effort is made to answer a simpler, yet necessarily primary, question. From the evidence of the recent past, have economic factors had any significant influence in determining fish landings, and, if so, how great has that influence been?

METHODS

The methods employed in this study are those of statistical correlation analysis. The author is aware of the ease with which spuriously significant results may be obtained by such methods. As the following will indicate, however, precautions

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against such dangers have been taken and, on the whole, the analysis tends to the conservative side both in statistical treatment and in interpretation.

Two variables are employed as economic factors in this study: (1) "Personal Expenditures in Canada on Consumer Goods and Services", as reported in the Dominion Bureau of Statistics' *National Accounts of Income and Expenditure*. This is rather a gross variable to use in correlation with fish landings and some consideration was given to using a food expenditure series or a perishable food series. Decision to use the total consumer goods expenditures series was based on the desire to underestimate rather than overestimate the degree to which explanatory value can be accorded the selected economic factors.

The consumers' expenditures variable is most appropriately regarded as an index of variations in the strength of effective demand in the economy at large. In a sense, it is employed as an index of business cycle fluctuations and the secular trend of the economy over the period in question. The series used is not the pure dollar series of Personal Expenditures in Canada on Consumer Goods and Services. Such figures would include the effects of the large changes in general price levels which have occurred in recent years. To eliminate such effects, the Dominion Bureau of Statistics' *deflated* series was employed. This series expresses the data in terms of constant dollars on a 1935-39 average base.

Because this series extends only as far back as 1926, the statistical analysis was confined to the period 1926-1950.

(2) The second economic factor considered was the landed price of the species in question. Since the problem involved is the extent to which changes in price may be said to be responsible for changes in the intensity of exploitation, the relevant variable is not the money price received by the fisherman, but its purchasing power. Consequently, the various price series were first deflated by the Dominion Bureau of Statistics' "Cost of Living" Index which is on a 1935-39 average base.⁴

Correlations and regressions have been computed using the methods described by Ezekiel [3]. The test for randomness of residuals (differences between observed catches and those predicted from the regression equation) is as given by Klein [4].

RESULTS

Table I shows the landings of eight kinds of fish that are of major importance in Canadian economy, for the years 1926 to 1950. In Table II is shown the average price per pound of each kind in each year, adjusted by the cost-of-living index to a 1935-39 basis. Table III gives personal expenditures on consumer goods and

⁴Correlation does not, of course, ordinarily determine which variable is cause and which effect. Fortunately for this case, however, the sign of the correlation indicates this. If price changes result from landings changes, high landings and low prices would go together, and vice versa. The regression coefficient would accordingly be *negative*. If landings changes result from price changes, high prices and high landings would go together and vice versa, and the coefficient would be *positive*. This neglects the existence of lags between the series, but the correlation chart can be read in each case to see if any exist.

TABLE I. Landings of selected Canadian fishes (in thousands of pounds, from [5]). "Atlantic" landings include the Maritime Provinces and Quebec, but exclude Newfoundland.

Year	Atlantic "sardine" herring	Atlantic cod	Atlantic herring	Pacific herring	Atlantic halibut	Atlantic lobster	Pacific halibut	Pacific salmon
1926	34,633	269,476	106,958	130,127	2,482	33,958	31,510	212,556
1927	34,939	197,864	93,667	172,425	2,850	31,683	30,053	149,040
1928	57,198	214,982	80,094	153,512	2,710	32,244	30,282	225,746
1929	49,839	197,883	94,758	131,567	3,190	37,282	30,392	151,404
1930	25,892	166,147	90,370	122,196	2,781	40,727	25,479	229,621
1931	12,732	146,200	92,216	148,108	2,892	43,549	18,201	128,704
1932	13,382	142,619	82,248	100,320	2,500	48,349	16,885	129,149
1933	26,097	155,648	94,515	107,737	3,001	37,492	17,081	141,050
1934	38,310	170,125	104,352	82,036	2,547	36,199	9,768	165,990
1935	37,533	152,246	101,728	100,851	3,020	31,997	10,193	178,943
1936	49,448	169,188	118,084	162,063	3,255	28,327	10,592	199,550
1937	31,896	150,932	107,747	192,980	3,337	30,995	11,721	169,174
1938	36,890	168,339	114,906	132,891	4,229	31,438	12,025	173,466
1939	63,437	161,918	113,839	216,481	5,077	31,466	13,397	147,637
1940	44,886	191,633	124,861	339,501	2,126	26,799	12,694	143,190
1941	88,747	194,754	105,107	168,852	2,024	27,802	12,929	190,035
1942	64,112	193,557	125,669	232,483	1,148	28,025	11,028	162,198
1943	79,276	213,938	136,265	182,794	1,217	30,109	12,687	121,421
1944	82,630	235,104	130,935	187,104	1,458	33,350	13,167	107,572
1945	67,779	291,075	127,948	257,654	1,352	37,180	14,905	170,965
1946	100,330	323,123	149,523	212,365	1,469	38,308	17,910	149,676
1947	101,586	231,276	137,780	256,331	1,918	31,884	24,119	162,800
1948	92,535	256,075	133,638	416,967	2,266	35,647	18,753	145,168
1949	62,097	246,284	123,706	344,527	4,217	38,205	17,997	147,368
1950	68,293	250,080	162,468	397,566	11,406	44,685	18,882	184,699

TABLE II. Average price to fishermen (in cents per pound, from [5]), adjusted by the cost-of-living index (1935-39 = 100). "Atlantic" prices include the Maritime Provinces and Quebec, but exclude Newfoundland.

Year	Atlantic "Sardine" herring	Atlantic cod	Atlantic herring	Pacific herring	Atlantic halibut	Atlantic lobster	Pacific halibut	Pacific salmon
1926	0.61	1.56	0.59	0.63	10.09	10.05	10.60	3.31
1927	0.48	1.45	0.61	0.65	10.28	10.43	9.27	4.59
1928	0.51	1.58	0.56	0.76	9.37	9.29	8.12	3.00
1929	0.60	1.68	0.64	0.60	10.69	8.48	9.61	3.97
1930	0.55	1.61	0.52	0.49	10.03	7.48	7.81	2.95
1931	0.45	1.28	0.51	0.39	9.70	6.85	5.82	2.35
1932	0.33	1.02	0.49	0.18	7.60	6.49	4.05	2.70
1933	0.47	1.15	0.49	0.46	8.11	6.48	5.38	3.35
1934	0.73	1.35	0.49	0.25	9.03	9.28	6.17	3.65
1935	0.77	1.25	0.53	0.29	8.19	10.30	6.70	3.59
1936	0.69	1.29	0.46	0.24	8.71	12.43	7.72	2.63
1937	0.65	1.33	0.44	0.23	9.03	11.96	7.82	3.08
1938	0.90	1.21	0.48	0.23	8.80	8.91	6.84	3.57
1939	0.90	1.23	0.48	0.23	8.40	9.18	7.13	3.89
1940	0.76	1.50	0.44	0.33	9.62	8.73	8.24	3.64
1941	0.94	1.85	0.49	0.35	9.60	9.37	8.60	5.38
1942	1.28	2.46	0.60	0.46	11.76	11.86	12.34	6.74
1943	1.37	2.96	0.79	0.63	13.74	16.39	15.96	5.01
1944	1.38	2.99	0.88	0.62	13.78	18.49	14.26	5.68
1945	1.38	3.05	0.94	0.63	13.92	22.02	14.59	5.51
1946	1.26	2.77	0.98	0.70	15.53	24.00	13.14	6.93
1947	1.13	2.04	0.80	0.71	15.24	19.15	11.89	5.70
1948	1.54	2.15	0.66	0.80	12.55	17.21	9.38	8.86
1949	1.25	1.87	0.66	0.75	13.23	16.60	9.62	6.60
1950	0.62	1.72	0.50	0.78	13.74	16.31	12.20	7.92

services, similarly adjusted. For convenient reference the cost-of-living index employed is shown in Table IV, though this is not used directly in the correlations.

The following symbols are employed:

- X_1 Annual catch series (in thousands of pounds)
- X_2 Consumer expenditure series (in millions of dollars)
- X_3 Average annual price series (in cents per pound)
- σ_b Standard error of regression coefficients (identified by numerical subscripts)
- \bar{R} Multiple correlation coefficient (corrected)
- \bar{r} Simple correlation coefficient (corrected)
- \bar{S} Standard error of estimate of regression equation (in thousands of pounds)
- U Test of randomness of residuals from regression equation
(Coefficient = 2 ± 0.7 indicates that residuals are randomly distributed)

TABLE III. Personal expenditure on consumer goods and services in Canada, 1926-50 (in millions of dollars, from [6]), adjusted by the cost of living index (1935-39 = 100).

Year	Expenditure	Year	Expenditure
1926	3,055	1939	3,820
1927	3,318	1940	4,127
1928	3,545	1941	4,432
1929	3,685	1942	4,622
1930	3,557	1943	4,679
1931	3,385	1944	5,030
1932	3,152	1945	5,471
1933	3,055	1946	6,189
1934	3,212	1947	6,478
1935	3,375	1948	6,368
1936	3,538	1949	6,612
1937	3,747	1950	6,857
1938	3,718		

TABLE IV. Cost-of-living Index (1935-39 = 100), from [7].

Year	Index	Year	Index
1926	121.8	1939	101.5
1927	119.9	1940	105.6
1928	120.5	1941	111.7
1929	121.7	1942	117.0
1930	120.8	1943	118.4
1931	109.1	1944	118.9
1932	99.0	1945	119.5
1933	94.4	1946	123.6
1934	95.6	1947	135.5
1935	96.2	1948	155.0
1936	98.1	1949	160.8
1937	101.2	1950	166.5
1938	102.2		

ATLANTIC "SARDINE" HERRING

Linear regression equation:

$$\begin{aligned}
 X_1 &= 16,110.338 + 9.312 (X_2) + 34,897.414 (X_3) \\
 \sigma_{b_{1,2,3}} &= 3.203 \\
 \sigma_{b_{1,2,3}} &= 11,197.051 \\
 \bar{R}_{1,23} &= 0.84 \quad \bar{R}_{1,23}^2 = 0.71 \\
 \bar{S}_{1,23} &= 13,980.629 \\
 U &= 2.02
 \end{aligned}$$

These results indicate that approximately 71 per cent of the experienced fluctuations in the annual catch of "sardines" is attributable to the selected economic factors. Both regression coefficients are of the order of three times their standard errors and are therefore statistically significant. The test of randomness of the residuals from the regression equation (U) indicates a clearly random distribution, which denotes the adequacy of the linear regression equation and substantiates the interpretation of the coefficient of determination, \bar{R}^2 .

ATLANTIC HERRING (MATURE)

Multiple correlation analysis, with consumer expenditures and price as independent variables, results in a regression equation containing a price coefficient only 0.2 the magnitude of its standard error. The price factor therefore cannot be regarded as a significant influence on Atlantic herring landings. Following are the results of simple correlation of landings with consumer expenditures alone.

Linear regression equation:

$$\begin{aligned}
 X_1 &= 53,019.109 + 14.014 (X_2) \\
 \sigma_{b_{12}} &= 1.933 \\
 \bar{r}_{12} &= 0.83 \quad \bar{r}_{12}^2 = 0.68 \\
 \bar{S}_{12} &= 11,883.575 \\
 U &= 1.46
 \end{aligned}$$

The consumer expenditure coefficient is very strong in this case, being more than seven times its standard error. The value of U is within the range of randomness, substantiating the interpretation that may be made from \bar{r}^2 that approximately 68 per cent of the variations in the annual Atlantic herring catch is due to changes in the general level of effective demand in the economy as indicated by the aggregate volume of consumer expenditures.

ATLANTIC COD

Study of the data reveals that Atlantic cod landings were particularly responsive to price changes. However, during the years of greatest war disturbance, the catch lagged behind the precipitous increase in price that occurred. As a consequence, the correlation analysis was carried out in this case with the years 1942-46 excluded. A multiple-regression equation for Atlantic cod, with consumer expenditures and price employed as independent variables, yields a value for the

consumer expenditure coefficient only 0.5 the magnitude of its standard error. It therefore appears that, in this case, the only economic factor of importance is the landed price. Simple correlation of cod landings with price for the twenty years 1926-41 and 1947-50 yields the following results.

Linear regression equation:

$$X_1 = 34,234.211 + 104,547.931 (X_3)$$

$$\sigma_{b_{13}} = 18,634.316$$

$$\bar{r}_{13} = 0.78 \quad \bar{r}_{13}^2 = 0.62$$

$$\bar{S}_{13} = 24,962.344$$

$$U = 0.92$$

The fact that the price coefficient is in excess of five times its standard error indicates that there can be little doubt that price is an important factor influencing Atlantic cod landings. We can, however, make only a *tentative* statement, based on \bar{r}^2 , that approximately 62 per cent of the catch fluctuations is due to price changes. This is due to the fact that the test of the residuals from the linear regression equation, as indicated by the value of U , displays a cyclical rather than a random distribution. Study of a scatter diagram of landings and price does not indicate that a curvilinear function is justified. It appears therefore, that some other factor or factors of a non-random nature such as, say, changes in the cod population have exerted an influence on the cod catch during the period under study. It is impossible to say what effect such factors, if they could be discovered and measured, would have on the results given above. As a consequence, this analysis of cod catch fluctuations must be regarded as tentative and, apparently, incomplete.

PACIFIC HERRING

Analysis of the Pacific herring catch yields results remarkably similar to those described above for Atlantic herring. In this case too the multiple correlation calculation results in the elimination of price as a significant factor. The price coefficient in the multiple regression equation is only 0.2 the magnitude of its standard error. Following are the results of simple correlation of Pacific herring landings with consumer expenditures.

Linear regression equation:

$$X_1 = -65,213.678 + 60.350 (X_2)$$

$$\sigma_{b_{12}} = 8.815$$

$$\bar{r}_{12} = 0.81 \quad \bar{r}_{12}^2 = 0.66$$

$$\bar{S}_{12} = 54,191.669$$

$$U = 1.84$$

Therefore, we may safely conclude that approximately 66 per cent of Pacific herring catch fluctuation is due to changes in aggregate consumer expenditures in the economy. This is especially interesting in view of the fact that the Pacific herring fishery has been, since 1936 at least, under catch quota regulations. The quota has not been a rigidly fixed one as in the case of halibut, and it appears

from the results given above that the quota has moved up and down in response to the demand for herring. If we compare the Pacific herring and Atlantic herring data we may perhaps conclude that the quota control of the former has regulated the annual catch nearly as well as the uncontrolled play of economic factors would have done.

ATLANTIC LOBSTER, PACIFIC SALMON, PACIFIC HALIBUT

In these three cases, the statistical results appear to be clearly negative. No significant correlation exists between catch and economic factors. This is as might be expected. Atlantic lobster and Pacific salmon are known to be exploited very intensively and one would expect that catch fluctuations would be dominated by changes in the magnitude of the stocks. Pacific halibut has been under strict quota regulation and hence no opportunity has been allowed for landings to respond to economic factors during the period studied.

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Cestode and Nematode Infection of Sockeye Smolts from Babine Lake, British Columbia¹

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ABSTRACT

Of the 1-year-old sockeye (*Oncorhynchus nerka* (Walbaum)) smolts migrating from Babine Lake in 1952 and 1953, in each year about 35% were infected with the cestode *Eubothrium salvelini* (Schränk, 1790) and 20% by the nematode *Philonema oncorhynchi* Kuitunen-Ekbaum, 1933. Six to 7% of the smolts harboured both parasites. Fish infected by cestodes only or cestodes and nematodes were significantly smaller than uninfected fish or those with nematodes only. This indicates that the cestode infection retards growth. Nematode-infected smolts were significantly larger than the uninfected individuals in 1952 but not so in 1953.

INTRODUCTION

SMOLTS of sockeye salmon, *Oncorhynchus nerka* (Walbaum), from Babine Lake, British Columbia, are infected with a cestode, *Eubothrium salvelini* (Schränk, 1790) and a nematode, *Philonema oncorhynchi* Kuitunen-Ekbaum, 1933.

The present study was undertaken to determine the frequency of infection by these parasites and whether or not the cestode or the nematode affected the growth of the fish.

Studies relating to the effects of parasites on the growth or weight of fishes appear to have been few in number. Hubbs (1927) showed that young *Platygobio gracilis* from a creek in New Mexico were markedly retarded in growth and development owing to heavy infections by larval trematodes in the visceral organs and larval proteocephalid cestodes in the intestine. He concluded that the parasitism by *Proteocephalus* was the greater contributing factor. Cross (1935) in a survey of the parasites of the perch in the Trout Lake region, Wisconsin, found that the growth of the fish was influenced by the degree to which they were parasitized. The perch harboured a wide variety of parasites, but Cross made no attempt to single out the effects of any one species. Hunter and Hunter (1938) exposed young smallmouth black bass to infection by cercariae of *Crassiphiala ambloplitis* (Hughes, 1927) and demonstrated that heavy infections caused a statistically significant loss in weight. The metacercariae of *C. ambloplitis* usually are found in the muscle. Miller (1945) discovered that larval *Triaenophorus* in the flesh of tullibee (*Leucichthys* sp.) and whitefish (*Coregonus clupeaformis*) retard the growth of these fishes. Bazikolova (1932) and Shulman (1948) (in Shulman and Shulman-Albova, 1953, pp. 82-83), working in Russia, found that *Contracaecum* sp. (larva) infection in codfish (*Gadus morhua*) livers caused a reduction in weight and oil content of the liver.

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METHODS

Random samples of sockeye smolts which had spent one year in the fresh water of Babine Lake were taken from traps operated to make population estimates (Withler, 1952 and 1953). The specimens were preserved in formalin and examined for fork length in millimeters, weight in grams, age from scale readings, and sex (Dombroski, 1952) at the Pacific Biological Station. Prior to being weighed, each smolt was dried externally and excess preserving fluid drained from the body cavity. The digestive tracts were examined for cestodes and the body cavities for nematodes. The stomach contents of the smolts were examined and found to consist almost entirely of copepods (*Heterocope*), cladocerans (*Daphnia* and *Bosmina*) and chironomid larvae.

The parasites were identified by Dr. L. Margolis, parasitologist at the Pacific Biological Station, as *Eubothrium salvelini* (Schrank, 1790) and *Philonema oncorhynchi* Kuitunen-Ekbaum, 1933.

Eubothrium salvelini (Schrank, 1790). This cestode was confined almost entirely to the pyloric caeca. An occasional specimen was found in the intestine. Infected smolts harboured from 1 to 5 cestodes. The parasite has been described by Nybelin (1922), Wardle (1932) and Kuitunen-Ekbaum (1933b). Wardle found heavy infections of this parasite in *Salvelinus alpinus malma* in Spray Lake, Alberta, which appeared to be responsible for an epizootic mortality among the young fishes.

Philonema oncorhynchi Kuitunen-Ekbaum, 1933. The nematodes were most frequently encountered loosely coiled about the pyloric caeca or along the mesenteries of the intestine or gonads. In some instances they were coiled tightly and adhered to the peritoneum between the body wall and the pyloric caeca. The female nematodes, because of their large size, were readily visible and numbered as many as 6 per fish. The males were small and usually coiled about the females. Kuitunen-Ekbaum (1933a), Smedley (1933) and Baylis (1948) have described this parasite.

RESULTS

The incidence of infection and the sizes of the 1-year-old smolts are given in Table I. Approximately one-third and one-fifth of the smolts in the samples of each year were parasitized by *Eubothrium* and *Philonema*, respectively. About 6 to 7% of the fish were infected by both parasites.

Table I indicates that 1-year-old smolts infected with cestodes are smaller than uninfected individuals. A "t" test (Fisher, 1950) proved that the observed differences in length were significant at $P = 0.01$.

From Table I it is also evident that smolts infected with nematodes appear to be somewhat larger than the uninfected group. The difference in the 1952 sample was significant at the $P = 0.01$ level, whereas in the 1953 sample it was not; however the combined effect is significant. Two possible explanations of such an effect may be offered: (1) since nematodes of this group commonly enter fish in the latter's food, then the larger smolts, which have presumably eaten more, have been more exposed to infection; (2) a section of the environ-

TABLE I. The average length and weight, and standard deviation in length and weight, of infected and uninfected 1-year-old smolts in 1952 and 1953.

	1952	1953
No. of 1-year-old smolts examined	1,654	1,234
No. found infected with both parasites	102 (6%)	87 (7%)
Av. length (mm.)	78.9 \pm 5.6	82.2 \pm 4.8
Av. weight (grams)	4.5 \pm 1.1	5.2 \pm 1.0
No. found infected with cestodes only	441 (27%)	380 (31%)
Av. length (mm.)	77.3 \pm 5.4	82.3 \pm 5.5
Av. weight (grams)	4.2 \pm 1.0	5.3 \pm 1.2
No. found infected with nematodes only	202 (12%)	137 (11%)
Av. length (mm.)	83.7 \pm 4.9	89.1 \pm 5.8
Av. weight (grams)	5.5 \pm 0.9	6.8 \pm 1.3
No. migrants uninfected	909 (55%)	630 (51%)
Av. length (mm.)	81.5 \pm 6.9	88.2 \pm 6.0
Av. weight (grams)	5.1 \pm 1.3	6.7 \pm 1.5

ment which favoured rapid growth because of higher temperature, for example, might also have more infective larvae.

As the doubly-infected group of migrants were found to be about the same size as the cestode-infected individuals, the apparent effect on growth is probably solely due to the cestode infection.

A chi-square test applied to the data indicated that there was no evidence that infection by one of the parasites affected the possibility of infection by the other, either positive or negatively.

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Some Helminth Parasites of Canadian Pacific Whales¹

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ABSTRACT

The following helminth parasites have been recorded from Cetacea caught off the British Columbia coast. Trematoda: *Lecithodesmus goliath* (fin whale), *Lecithodesmus spinosus* n. sp. (sei whale) and *Ogmogaster plicatus* (fin and sei whales); Cestoda: *Phyllobothrium delphini* (sperm and fin whales); Nematoda: *Anisakis simplex* (sei, Baird's beaked and sperm whales), *Anisakis physeteris* (sperm whale), immature *Anisakis* sp. (fin and humpback whales) and *Crassicauda pacifica* n. sp. (fin whale); Acanthocephala: *Bolbosoma turbinella* (sei whale). *Crassicauda pacifica* and *L. spinosus* are illustrated and described, and compared with known species of their respective genera. The variations in morphology and measurements are discussed for *O. plicatus*. Notes on host and geographical distribution are cited for all parasites. *Lecithodesmus goliath* and *O. plicatus* are reported for the first time from the Pacific and *P. delphini* was previously unknown in the North Pacific. *Bolbosoma turbinella* is a new record for the northeast Pacific and *A. physeteris* for the Pacific coast of Canada. Baird's beaked whale and possibly the sperm whale are new host records for *A. simplex*. The fin whale is a new host record for *P. delphini* and *L. goliath*.

INTRODUCTION

THE only helminth parasite from Cetacea of the Pacific coast of Canada that has been recorded in the literature to date is *Anisakis simplex* (Rudolphi, 1809), which has been reported from *Balaenoptera borealis*, the sei whale, by Mueller (1927a, b) and Cornwall (1928).

There are several records of worm parasites of Cetacea from other parts of the west coast of North America. Leidy (1886) reported *Ascaris* (= *Anisakis*) *simplex* from an unidentified species of dolphin in the Pacific. Price (1932) described *Hadwenius seymouri* (= *Odhneriella seymouri* (Price, 1932) Skrjabin, 1944), a new trematode species inhabiting the intestine of *Delphinapterus leucas* in Alaskan waters. Scheffer (1939) cited *Anisakis physeteris* Baylis, 1923, as a parasite of the sperm whale in Alaska. Dougherty (1943a, b, 1944) reported the lung nematodes, *Stenurus vagans* (Eschricht, 1841), *Pharurus convolutus* (Kuhn, 1829) and *Halocercus invaginatus* (Queckitt, 1841) from *Phocoena phocoena* (i.e. *vomerina*), and described a fourth species as new, *Halocercus kirbyi* Dougherty, 1944, from *Phocoenoides dalli*. The porpoises were taken on the California and Washington coasts. Scheffer and Slipp (1948) mentioned the presence of helminths, particularly stomach nematodes and tapeworm larvae in the blubber, in some Cetacea from Washington coastal waters, but none were identified to species and only one nematode was identified to genus—a species of *Anisakis* from *Grampus rectipinna*. These same authors also referred to Dougherty's identification of *Pharurus convolutus* and *Halocercus invaginatus*.

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from the lungs of *Phocoena vomerina*. Van Cleave (1953) briefly described specimens of *Bolbosoma balaenae* (Gmelin, 1780) from an unidentified species of whale stranded near Seattle.

The parasites recorded in this paper were collected mainly during the years 1949 to 1952 at the Coal Harbour whaling station, situated on the west coast of Vancouver Island. A few additional specimens were obtained in the summer of 1953.

TREMATODA

Family CAMPULIDAE Odhner, 1926

Genus *Lecithodesmus* Braun, 1902

Lecithodesmus goliath (van Beneden, 1858) Odhner, 1905

Ten mature specimens were collected from the bile ducts along the posterior margin of the liver of a fin whale, *Balaenoptera physalus*.

This is the first Pacific record of *L. goliath* and the only report of a liver fluke in the fin whale. The parasite was previously known from *Balaenoptera acutorostrata*, *B. borealis* and *Balaena mysticetus* in northwestern European seas.

Descriptions and illustrations of this trematode are to be found in Braun (1902), Odhner (1905), Price (1932) and Dawes (1946). Braun and Odhner examined original material. Price and Dawes based their descriptions on the work of earlier authors.

The present collection extends the lower limits of the size range, but shows no significant morphological differences from the European material. However, several characters are worthy of comment.

Odhner suggested that the living worm probably is completely spined, although he observed only traces of spination in the anterior region. Since he examined old and poorly preserved specimens he was led to believe that the lack of complete spination was due to the effects of maceration. Our specimens, which were living when collected, and fixed immediately in Bouin's solution, reveal cuticular spines to be lacking. However, in the anterior region there appear to be traces of formerly existing spines, as described by Odhner. These probably represent the remnants of a spination that was present in the metacercaria.

The present examples are thicker than those recorded by Odhner, but this dimension is greatly modified by the amount of pressure applied to the specimens at fixation.

Odhner quoted the cirrus length as 3-4 mm. The specimens at hand indicate that the protruded cirrus may be as long as 6 mm.

The full diameter of the acetabulum which apparently can only be seen when examining median sagittal, frontal or transverse sections, is about 1.8 mm., as recorded by Odhner. Braun, who did not examine sections, gave the diameter as 1.3 mm. This diameter applies only to the portion of the acetabulum that is visible externally. Because of the thickness of the trematode, whole

specimens do not clear readily, particularly in the region of the acetabulum, and the true diameter of this organ usually is not visible in whole mounts.

In the European material the oral sucker has been described as considerably larger than the ventral sucker. This appears to apply to our specimens when they are examined externally. In reality, however, the suckers are very similar in size. The oral sucker, which is smaller than recorded by Braun and Odhner, is a little larger, equal to or a little smaller than the acetabulum.

Table I compares measurements of European and Pacific *L. goliath*.

Lecithodesmus spinosus n. sp. (Fig. 1-3).

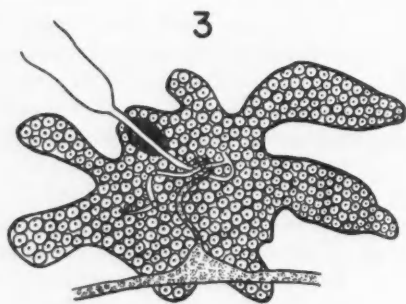
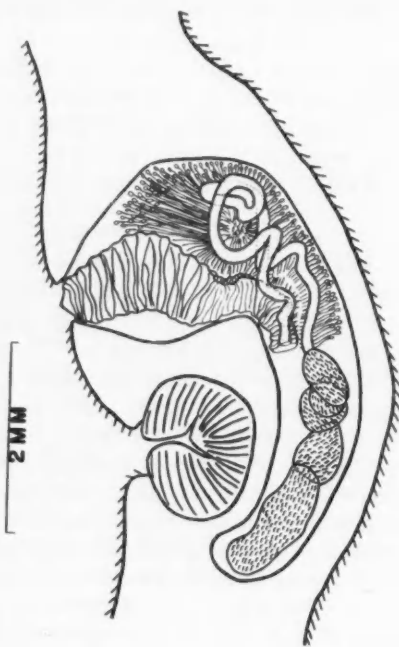
Specimens of this new species of trematode were recovered from two sei whales, one caught in 1951 and the other in 1953. One host yielded more than 50 of these flukes.

DESCRIPTION: This trematode is 27-44.8 mm. long by 6.6-11.5 mm. maximum width at the level of the testes, tapering anteriorly and posteriorly. In extended specimens the body tapers posteriorly more acutely than anteriorly. In contracted individuals the reverse may be true. Width-to-length ratio is variable, depending on the state of contraction of the body musculature. The body is flat, 1.3-2.0 mm. thick just anterior and posterior to the cirrus pouch and diminishing gradually toward the extremities, particularly posteriorly. There is a marked dorsal expansion in the region of the cirrus pouch, where the body is up to 3 mm. thick. The anterior end is bluntly rounded, the posterior extremity more pointed, sometimes appearing to possess a small nipple-like projection. The body is constricted laterally at the level of the acetabulum. The cuticle is armed with deeply embedded spines, 50-80 μ long.

The oral sucker is subterminal to terminal, 1.30-1.90 mm. in diameter, 0.75-1.10 mm. deep, with a circular aperture, 0.75-1.40 mm. in diameter. The acetabulum, 10-16.3 mm. behind the oral sucker (i.e. in the extreme anterior portion of the middle third of the body), is oval-shaped, a little smaller or a little larger than the oral sucker, 1.26-1.61 mm. in longitudinal diameter, 1.61-1.84 mm. in transverse diameter and 0.90-1.20 mm. deep. The oval-shaped aperture of the acetabulum is 0.56-0.97 mm. in transverse diameter.

The prepharynx is 0.15-0.20 mm. long. Frequently it is not apparent in contracted specimens where the pharynx is drawn up to the base of the oral sucker. The pharynx is oval-shaped with a narrow lumen, 1.1-1.5 mm. long by 0.55-0.70 mm. wide. The oesophagus is very short, divides almost immediately into two intestinal crura that extend to the posterior end of the body and end blindly. Near their origin, the crura each give rise to an anterior branch which extends to the level of the oral sucker and gives off 3 to 5 lateral diverticula along its length. The lateral diverticula may be secondarily divided into two branches. The main intestinal caeca give off numerous lateral and median branches which themselves are branched, except for those in the posterior-most region.

The post-acetabular testes, about 1.75-3 times as wide as long, lying ventral to the caeca, are tandem, branched and extend almost the complete width of the body. The anterior testis is somewhat smaller than the posterior one. The



anterior-most extent of the branches of the anterior testis lie a short distance caudad to the middle of the body. The cirrus pouch proceeds dorsally and slightly to the right of the midline, from the median, ventral, pre-acetabular genital pore. Behind the acetabulum it turns posteriorly and passes, in a slightly sinuous course, to the right of the midline, dorsal to the uterus and acetabulum. It extends posteriorly to about one-third to one-half the distance between the acetabulum and ovary. The ventro-dorsally directed portion has a maximum diameter of about 1.80 mm. and the backwardly directed portion is about 0.60–0.70 mm. in diameter. The cylindrical seminal vesicle, about 0.35–0.45 mm. in diameter, occupies most of the posterior half of the cirrus pouch, reaching anterior to the acetabulum. Its anterior half is coiled. A long, sinuous prostatic duct, surrounded by numerous prostatic cells, joins the seminal vesicle and the unspined cirrus. The cirrus is frequently found protruding from the common genital pore. When the cirrus is in this position the prostatic duct apparently straightens out. When retracted, the cirrus occupies a large part of the ventro-dorsally directed portion of the cirrus pouch and reaches posteriorly to a little in front of the seminal vesicle. The retracted cirrus measures 2–2.5 mm. long. When protruded, the cirrus measures up to 4.2 mm. long.

The ovary, much smaller than the testes, is deeply lobed, 2–3 times as wide as long and lies just in front of the anterior testis, slightly to the right of the midline. The lateral branches of the testis actually extend as far forward as, or even slightly anterior, to the ovary. The distance between ovary and acetabulum varies between equal to and three times the distance between acetabulum and genital pore. Laurer's canal is slightly coiled and opens dorsally to the left side of the main body of the ovary. A seminal receptacle was not seen. Mehlis' gland is dorsal to the left portion of the ovary. The uterus is entirely pre-ovarian, intra-caecal, convoluted and leads into an unspined metraterm that turns back on itself to open to the common genital atrium close to the cirrus. The thick shelled ova, 108–112 μ by 70–72 μ , are triangular in cross-section.

The vitellaria are massive, arranged in groups and occur from the level of the transverse portion of the intestine to almost the posterior extremity. They are found throughout the depth of the worm and are most concentrated anterior to the genital pore where they extend across almost the entire width of the body. Between the genital pore and the posterior limit of the testes they occupy mainly the lateral regions, with a few groups scattered medially in the region of the testes. Behind the testes they again occur medially as well as laterally. The anterior vitelline ducts consist of a single median canal that divides into two ducts

FIGURES 1–3. *Lecithodesmus spinosus* n. sp.

(Figures 1 and 2 are drawn with the aid of a camera lucida, 3 is a freehand drawing.)

1. *Toto* mount, ventral view.
2. Male terminal genital ducts, lateral view, as drawn from thick sagittal section and partially reconstructed from thin serial sagittal sections.
3. Ovarian complex, dorsal view.

that run posteriorly in the lateral zones and then turn medially in the region of the ovary to join the common transverse ducts at or near the posterior level of the ovary. The anteriorly directed vitelline ducts arise in the posterior region of the body, one on each side of the excretory vesicle. They unite to form a short duct that follows an anterior course ventral to the excretory duct. This duct bifurcates posterior to the testes, the two ducts running forward in the lateral regions to join the common transverse ducts. There are many small median and lateral collecting vessels uniting with these main ducts. The vitelline reservoir is small, oval-shaped and lies dorsal or postero-dorsal to the left half of the ovary.

The excretory vesicle is tubular, median and reaches to the level of the ovary. The excretory pore is terminal.

The type specimen is to be deposited in the National Museum, Ottawa, Canada. Paratypes are in the collection of the Pacific Biological Station. The type host is the sei whale, *Balaenoptera borealis*.

Lecithodesmus spinosus is the third species of the genus to be described. The others are *L. goliath* and *L. nipponicus* Yamaguti, 1942, from *Delphinus longirostris* and *Globicephalus scammoni* from Japan. The new species can be differentiated readily from the other species on the basis of size. It is considerably larger than *L. nipponicus* and shorter, thinner but relatively broader than *L. goliath*.

The new species also differs from *L. goliath* in width-to-length ratio of the testes. In *L. goliath* the testes are much longer than wide, whereas the width is greater than the length in *L. spinosus*. The cuticular spines in *L. spinosus* are very numerous and completely cover the cuticle, whereas in *L. goliath*, only suggestions of cuticular spination are present anteriorly.

The eggs of *L. nipponicus* are considerably smaller than those of *L. spinosus* and the cirrus pouch extends posteriorly only to the level of the anterior margin of the acetabulum, whereas in the new species it extends beyond the acetabulum. The shape of the pharynx and its lumen differ markedly in the two species.

Table I compares measurements of *L. spinosus*, *L. nipponicus* and *L. goliath*.

Family NOTOCOTYLIDAE Lühe, 1909

Genus *Ogmogaster* Jägerskiöld, 1891

Ogmogaster plicatus (Creplin, 1829) Jägerskiöld, 1891. (Fig. 4-6)

This trematode was present in the small and large intestines of about 10% of the fin and sei whales examined. It has been described from these two hosts in Norwegian waters (Creplin, 1829; Jägerskiöld, 1891) and recorded from the sei whale of South Africa and South Georgia (Matthews, 1938), but has not been recorded previously from the Pacific. It is also known to parasitize seals (*Leptonychotes weddelli* and *Lobodon carcinophaga*) of the Antarctic (Leiper and Atkinson, 1915; Johnston, 1931, 1937).

The original account by Creplin (1829) of *Monostomum* (= *Ogmogaster*) *plicatum* was based on specimens collected from a whale which was identified

TABLE 1. Comparison of measurements (in millimeters, except where otherwise indicated) of *L. spinosus*, *L. nipponicus* and *L. goliath* from Europe and the Pacific.

	<i>L. goliath</i>		<i>L. spinosus</i>		<i>L. nipponicus</i>	
	Europe	Pacific				
Body—						
Length	60-80	50-61	27-44.8		9-27	
Breadth (maximum)	8-10.5	6.5-9.0	6.6-11.5		1.4-3.3	
Thickness (behind cirrus pouch)	1.6-1.8	1.9-2.8	1.3-2.0		...	
Oral sucker—						
Diameter	2.3	1.70-1.82	1.30-1.90		0.6-1.25 × 0.8-1.6	
Depth	2	1.47-1.50	0.75-1.10		...	
Aperture (diam.)	...	0.84-0.91	0.75-1.40		0.5-1.3	
Ventral sucker—						
Longitudinal diameter	1.8	1.55-1.75	1.26-1.61		0.6-1.45	
Transverse diameter	...	1.75-1.96	1.61-1.84		0.6-1.45	
Depth	1.6	1.4-1.6	0.90-1.20		...	
Aperture (transverse diam.)	...	0.70-0.90	0.56-0.97		...	
Ratio of long. diam. V.S. : diam. O.S.	1:1.28	1:1-1.29	1:0.94-1:1.29		1:1.10-1:1.33	
Distance of O.S. to V.S.	28	19.0-22.4	10-16.3		...	
Prepharynx—length	short	0.14-0.18	0.15-0.20		short	
Pharynx—						
Length	1.50	1.33-1.50	1.1-1.5		0.41-1.0	
Breadth	0.70-0.95	0.63-0.70	0.55-0.75		0.33-0.75	
Distance of genital pore to V.S.	...	1.3-1.75	0.40-1.00		0.17-0.40	
Distance of V.S. to ovary	...	2.2-2.85	1.05-1.96		...	
Ovary—						
Length	...	1.05-1.40	0.55-1.1		0.27-0.82	
Breadth	...	1.8-2.1	1.3-2.3		0.5-1.25	
Testes—						
Length	...	6.3-7.9	2.1-5.9		0.5-2.6	
Breadth	...	6.3-6.8	5.8-9.8		0.65-2.5	
Cirrus—length	3-4	4.6-6	3.6-4.2		...	
Ova—						
Length	104-120 μ	105-112 μ	108-112 μ		60-72 μ	
Breadth	62-75 μ	63-70 μ	69-73 μ		45-54 μ	
Spines—length	none	none	50-80 μ		60 μ	



FIGURES 4-6. *Ogmogaster plicatus* (Jägerskiöld, 1891)

Photographs of *toto* mounts, ventral view, of 3 specimens showing some of the variations in morphology discussed in the text.

4. Specimen 6.9 by 4.8 mm. 5. Specimen 12.5 by 5.9 mm. 6. Specimen 13.4 by 5.8 mm.

as *Balaenoptera rostrata* (= *acutorostrata*). Baylis (1916) pointed out that this whale, from which Creplin also described the nematode *Filaria* (= *Crassicauda*) *crassicauda*, was more likely the fin whale, *B. physalus*. *Balaenoptera physalus* is thus the type host. Jägerskiöld (1891) cited *B. borealis* and *B. musculus* as hosts. Leiper and Atkinson (1915) and Price (1932) indicated that the latter whale was actually *B. physalus*, the common rorqual or fin whale. Baylis (1932) listed the cetacean hosts as *B. borealis*, *B. physalus*, *B. musculus* and *B. acutorostrata*, whereas Price (1932) and Dawes (1946) did not consider *B. musculus* as a known host of *O. plicatus*. It is also doubtful that *B. acutorostrata* harbours this parasite. The two definitely known hosts are *B. physalus* and *B. borealis*.

An exhaustive morphological treatment, with figures, of *O. plicatus* from whales in Europe has been published by Jägerskiöld (1891), and a briefer characterization by Price (1932) (mostly taken from Jägerskiöld). Leiper and Atkinson (1915) briefly described and illustrated specimens from Antarctic seals. Johnston (1931, 1937) regarded the species of *Ogmogaster* in Antarctic seals as distinct from *O. plicatus* and described in detail, with illustrations, specimens from *L. weddelli* as a new species, *Ogmogaster antarcticus*. Price and Dawes (1946) considered *O. antarcticus* a synonym of *O. plicatus*.

Table II compares measurements of the present material with the European specimens from whales and the Antarctic specimens from seals. The measurements of the Pacific examples include the smallest and largest individuals collected.

TABLE II. Comparison of measurements of Atlantic, Pacific and Antarctic specimens of *Ogmogaster plicatus*.

	Atlantic (whales) (Jägerskiöld: Price)	Pacific (whales) (present specimens)	Antarctic (whales) (Johnston)	Antarctic (seals) (Leiper & Atkinson)
Length	6-14 mm.	4.3-14.5 mm.	5-6.7 mm.	5-8 mm.
Width (max.)	4 mm.	2.7-6 mm.	3.5-5.5 mm.	4.5-5.5 mm.
No. of longitudinal rugae	15-17	13-25	13	14-15
Oral sucker (diam.)	...	0.42-1.05 mm.	0.5 mm.	0.5 mm.
Aperture of oral sucker (diam.)	...	0.21-0.55 mm.	...	0.25 mm.
Excretory pore to posterior end of body	0.7 mm.	0.45-1.29 mm.	...	...
Cirrus pouch	3×0.3 mm.	$1.45-6.8 \times 0.32-0.9$ mm.	1.8×0.34 mm.	...
Seminal vesicle	1.4×0.2 mm.	$0.60-3.0 \times 0.17-0.40$ mm.	...	...
Testes	1×1.1 mm.	$0.70-1.73 \times 0.91-1.80$ mm.	$0.7-0.9 \times 0.6-0.7$ mm.	...
Ovary	0.5×1.0 mm.	$0.25-0.80 \times 0.60-0.88$ mm.	0.4×0.6 mm.	...
No. of vitelline follicles on each side	12-16	11-18	10-18	10-18
Ova	25μ long	$23-28\mu \times 12-13\mu$	$20\mu \times 12\mu$	...
Egg filaments (length)	...	100-150 μ	160 μ	...

The measurements cited for European specimens were apparently for the smallest individual encountered (i.e. about 6–7 mm. long), since they correspond to the measurements of Pacific individuals of the same length. Jägerskiöld stated that most of his specimens were between 6 and 7 mm. long, but he gave the maximum length as 14 mm. In the present collection of several hundred specimens, more than one-half of the individuals are from 11–14 mm. long. Since there was selective collection of the larger specimens, this is not a true indication of the relative abundance of large specimens in the host.

From the examination of about 200 specimens certain morphological characters, some of which vary with the length of the body, were noted to be highly variable.

The length-to-width ratio of the body probably depends to a large extent on the state of contraction and flattening when fixed. One specimen in the present collection, of length 6.3 mm., is more than 5 mm. in maximum width, whereas others up to 10 mm. long are only 4–5 mm. wide. The cirrus pouch is one-third to one-half as long as the body. In the small specimens it is usually close to one-third and in the large specimens it is nearly always one-half. The anterior extent of the vitelline follicles varies from one-third the distance between testes and base of the cirrus pouch to the total distance, but is independent of body length.

The following three characters seem to depend largely on the length of the fluke. The number of longitudinal rugae increases from 13 in specimens less than 5.5 mm. long to a maximum of 25 in individuals 11–14 mm. long. The ovary length-to-width ratio is considerably less than 1:1 in small specimens, approaches 1:1 in specimens 7–10 mm. long and may exceed 1:1 in specimens of length 11–14 mm. The pleated appearance and inrolling of the margins is very pronounced in small individuals and usually scarcely, if at all, noticeable in the large specimens.

Johnston (1931, 1937) considered his specimens from Antarctic seals to differ from *O. plicatus* of whales by virtue of their smaller size, different ratio of length to width of body, presence of only 13 rugae, relatively smaller cirrus sac and in the more restricted anterior extent of the vitelline follicles. The detailed morphological study of many specimens in the present collection indicates that Johnston was dealing with small specimens of *O. plicatus*, and accordingly *Ogmogaster antarcticus* Johnston, 1931, is a direct synonym of *O. plicatus* (Creplin, 1829), as suggested by Price (1932).

CESTODA

Family PHYLLOBOTHRIIDAE Braun, 1900

Genus *Phyllobothrium* van Beneden, 1849

Phyllobothrium delphini (Bosc, 1802) van Beneden, 1870

Cysts, containing this larval phyllobothriid, were invariably found in the blubber of the sperm whale, *Physeter catodon*. A single specimen was recovered from a fin whale, which appears to be a new host record for this cestode species

and the first report of *P. delphini* in a baleen whale. The extensive host tissue reaction, in the form of a thick connective tissue capsule, as evidenced in the fin whale, is entirely lacking in the sperm whale. This suggests that the fin whale probably was an abnormal host for this tetraphyllidean larva.

Cysts of tapeworm larvae in the blubber and muscle of Odontoceti of the Northeastern Pacific have been noted previously by Scheffer and Slipp (1948), but the cestodes were not identified.

Specimens of a tapeworm cyst in the blubber of a sperm whale were first mentioned by Bennett (1837). He recorded finding numerous cysts of a species of cysticercus in the sperm whale, but failed to describe them. Diesing (1850), having misinterpreted Bennett's statement regarding the host, named the parasite *Cysticercus Balaena mysticeti* Bennett. Diesing (1863) later corrected his error and renamed the parasite *Cysticercus physeteris* Bennett. Pouchet (1888) also recorded tapeworm cysts in the blubber of a sperm whale caught near the Azores, but failed to describe the specimens. Meggitt (1924) placed *C. physeteris* in the genus *Phyllobothrium*. Baylis (1932) listed the parasite as *Phyllobothrium physeteris* (Diesing, 1863) Meggitt, 1924, stating that it was a possible synonym of *P. delphini* (Bosc, 1802). Subsequent authors have regarded *P. physeteris* as either definitely or possibly specifically identical with *P. delphini*. A description of the original specimens of *P. physeteris* (i.e. *Cysticercus physeteris* Diesing) is nonexistent. The present material from the sperm whale agrees in all particulars with published descriptions of *P. delphini* and thus strengthens the view that the original material from a sperm whale referred to as *P. physeteris* is identical with *P. delphini*.

Recent descriptions of this parasite are to be found in papers by Southwell and Walker (1936), Adam (1938), and Johnston and Mawson (1939). Wardle and McLeod (1952) gave a brief characterization of this cestode larva.

Phyllobothrium delphini is a common parasite of odontocete cetaceans and some pinnipeds in both the northern and southern hemispheres.

NEMATODA

Family ANISAKIDAE Skrjabin and Karokhin, 1945

Genus *Anisakis* Dujardin, 1845

Anisakis simplex (Rudolphi, 1809) Baylis, 1920

This common nematode of cetaceans was present in the stomach of a few sei whales, from which host in British Columbia it was previously recorded by Mueller (1927a, 1927b) and Cornwall (1928).

Five males and 8 females from the stomach of a Baird's beaked whale (*Berardius bairdi*) were identified as *A. simplex*. About 50 larval and immature worms of the genus *Anisakis* were taken from this same whale. They probably belong to *A. simplex*. This is a new host record for this universally distributed nematode.

Anisakis simplex was collected from some sperm whale stomachs, occasion-

ally in large numbers. Baylis (1929) described *Anisakis catodontis* from a single mature male and several immature forms from a sperm whale caught in the Atlantic near South Africa. Johnston and Mawson (1943, 1945) considered *A. catodontis* a synonym of *A. simplex*. If Baylis' specimens correctly belong to the species *A. simplex* then the present record constitutes the second in *Physeter catodon*.

Anisakis simplex parasitizes a wide variety of odontocete and baleen Cetacea, its host range apparently being restricted only by the feeding habits of the whale. Dollfus (1948) gave a fairly complete account of the known cetacean hosts of nematodes of the genus *Anisakis*.

Stiles and Hassall (1899) reviewed the confused early literature on *A. simplex* and related species and repeated the descriptions of the earlier authors. Lyster (1940) presented a detailed description of specimens obtained from the white whale, *Delphinapterus leucas*, in the Gulf of St. Lawrence, Quebec. He considered *Anisakis typica* (Diesing, 1861), *Anisakis dussumieri* (Van Beneden, 1870) and *Anisakis kukenthali* (Cobb, 1888) as synonyms of *A. simplex*, a view upheld by the present authors. He discussed the variation in size of the worms as well as individual structures and the variation in distribution of the caudal papillae in the male. Yamaguti (1942b) described specimens of *A. simplex* as *Anisakis salaris* (Gmelin, 1890) Yamaguti, 1935 from *Globicephalus scammoni* of Japan. Johnston and Mawson (1942) briefly described specimens from *Lagenorhynchus obscurus* from Cook Strait, New Zealand. Their description conforms to that of Lyster.

Kreis (1952) reinstated *Anisakis typica* (Diesing, 1861) as a valid species and very adequately described and illustrated specimens obtained from the Copenhagen Museum in 1938. The material had been collected by Suenson from *Hyperoodon rostratus* from the Faroe Islands and previously had been identified as *A. simplex*. The specimens are probably some of those upon which Krabbe (1878) based his description of *A. simplex*, since the host, locality and collector are the same as recorded by Krabbe for some of the material he examined. Furthermore Krabbe worked in Copenhagen and probably deposited his specimens in the Museum.

Kreis cited the following five morphological characters as differentiating *A. typica* and *A. simplex*.

- (1) Primary cuticular striations secondarily divided into finer striae in *A. simplex* but not in *A. typica*.
- (2) Cervical papillae absent in *A. simplex*, present in *A. typica*.
- (3) Spicules equal in length in *A. simplex*, very unequal in *A. typica*.
- (4) Egg shell of *A. simplex* with roundish elevations, smooth in *A. typica*.
- (5) Teeth of labial dentigerous ridges small in *A. simplex*, larger and more prominent in *A. typica*.

From Kreis's discussion it is evident that he has not examined examples of what he considers typical *A. simplex*. The differential characters apparently are based mainly on the diagnosis of *A. simplex* as first cited by Stiles and Hassall (1899) and later by Baylis (1923) and Schuurmans-Stekhoven (1935). Stiles

and Hassall (1899) constructed their diagnosis from the descriptions of Krabbe (1878) and Linstow (1888) and not from original examination of specimens. Baylis and Schuurmans-Stekhoven apparently followed Stiles and Hassall. It must be pointed out that Rudolphi's descriptions (in Stiles and Hassall, 1899) of *A. simplex* do not permit recognition of the species, and Krabbe's description of *A. simplex* has been used as the basis for identification of this species. His description, nevertheless, is far from adequate. Linstow's specimens have been redetermined by Baylis (1916a) as *Ascaris* (i.e. *Porrocaecum*) *decipiens* (Krabbe, 1878). [The host, according to Baylis (1937), was the seal, *Arctocephalus gazella* (recorded as *Otaria jubata* by Linstow) from Kerguelen. All other records of *A. simplex* are from cetaceans.] It follows, then, that the characters that Linstow described for *A. simplex*, and incorporated into the diagnosis of this species by Stiles and Hassall, Baylis (1923) and Schuurmans-Stekhoven (1935), in reality do not apply to it. These are exactly some of the main differential characters utilized by Kreis (1952); namely, equal spicules, secondary cuticular striations and rounded elevations on the egg shell of *A. simplex*. These characters were not mentioned for *A. simplex* by Krabbe (1878) or later authors (excepting Linstow, 1888) who examined original material.

Thus there are only two of Kreis' differential characters left for discussion. The cervical papillae were not mentioned by Krabbe for *A. simplex* or *A. typica*, but this does not imply that they are lacking. Stiles and Hassall described and illustrated cervical papillae in *A. typica* (from specimens examined). They also cite cervical papillae as being present in *A. simplex* but it is not clear on whose authority this is based, since they did not examine individuals of *A. simplex* (*sensu* Stiles and Hassall, 1899). Other early authors failed to mention the presence or absence of cervical papillae in *A. simplex*, but this certainly does not indicate that they are absent. With regard to the teeth of the labial dentigerous ridges, it seems to the present authors that very little can be inferred from the early literature, except that they have been described as present in *A. simplex* and *A. typica*. Drasche (1883) illustrated them as exceptionally prominent in *A. typica*, but there appears to be no difference in the size of the teeth in Krabbe's (1878) illustrations of *A. simplex* and *A. typica*.

It is apparent then, that no species of *Anisakis* is known to exist that possesses the differential characters described by Kreis for *A. simplex*, with all other characters identical with *A. typica*.

Krabbe's (1878) descriptions of *Ascaris* (i.e. *Anisakis*) *simplex* and *A. typica* (= *Ascaris conocephalus*) indicated that the two species could be separated on the basis of the distribution of the tail papillae in the male and the degree of construction of the anterior projection from the base of the dorsal lip. The present observations confirm those of Lyster (1940) and other workers in that neither of these characters is sufficiently constant to be considered useful in separating *A. simplex* from *A. typica*.

Schuurmans-Stekhoven (1935) believed the ventriculus in *A. typica* to be S-shaped and that of *A. simplex*, straight. As stated by Lyster, Kreis and others the shape of the ventriculus cannot be relied upon as a specific character.

Since there are apparently no morphological features by which *A. typica* can be differentiated from *A. simplex*, we are inclined to the view that *A. typica* is a synonym of *A. simplex*. This is further borne out by the fact that Kreis's description of *A. typica* is almost certainly based on some of the specimens which Krabbe determined as typical examples of *A. simplex* (Rudolphi, 1809).

It is worthy of note that, prior to Krabbe's (1878) work, Dujardin (1845) published a description of specimens of *Ascaris simplex* Rudolphi, 1809, taken from a dolphin near the Maldives. The cuticle was described with only primary striations, rounded elevations were not described as present on the egg shell and the spicules were unequal in length. Cervical papillae were not mentioned, nor were the labial teeth described in detail. The lengths of the spicules were cited as 27 mm. and 15 mm. There was probably an error in the decimal point, the correct lengths being 2.7 and 1.5 mm. Van Beneden (1870) did not examine Dujardin's specimens but created a new species, *dussumieri*, for them. Linstow (1888) failed to believe that the specimens belong to the genus *Ascaris*, but it has been pointed out already that at that time Linstow had a misconception of the species *A. simplex*. Stiles and Hassall (1899) considered Dujardin's *A. simplex* as probably identical with *A. typica*. It is our belief that Dujardin (1845) was the first author after Rudolphi to examine the species *A. simplex* (Rudolphi).

In the present specimens the spicules are unequal, the right one measuring about 1.3–2.6 mm. and the left one 2.8–3.8 mm. long. The cervical papillae are present, secondary cuticular striations are absent and the egg shell is smooth. The arrangement of the post-cloacal papillae varies within the limits described by Lyster (1940). The ventriculus is straight in some specimens, but most frequently sigmoid. The vulva lies close to the middle of the body.

Anisakis physeteris Baylis, 1923

Large numbers of *A. physeteris* were found in the stomachs of all sperm whales examined. The sperm is the only known host of this nematode. Occasionally, *A. simplex* was found along with *A. physeteris*.

In the North Pacific, Scheffer (1939) recorded this parasite from the sperm whale caught in the vicinity of the Aleutian Islands, Alaska, and Yamaguti (1942) described it from this host in Japanese seas. It was originally described by Baylis (1923) from South Georgia and later recorded (Baylis, 1929) from Durban and Saldhana Bay, South Africa, as well as South Georgia. Johnston and Mawson (1945) again reported this worm (as *Stomachus physeteris*) from the sperm whale at Durban, and Rees (1953) identified it from the stomach of sperm whales taken in the Ross Sea area. *Anisakis physeteris* probably parasitizes the sperm whale throughout its distribution.

Anisakis sp. (spp.)

Immature nematodes belonging to the genus *Anisakis* were found in the stomach of a humpback whale, *Megaptera nodosa*. The larger specimens appeared to belong to *A. simplex* but owing to their immaturity they could not

be identified with certainty. One other record of *Anisakis* in the humpback whale has appeared in the literature (Baylis, 1929). This whale was caught at Durban and only immature worms were reported.

Four specimens were taken from a fin whale, but owing to their immaturity they could not be specifically identified. Wülker (1930) described *A. simplex* from this host in the North Sea.

Family CRASSICAUDIDAE Skrjabin and Andreewa, 1934

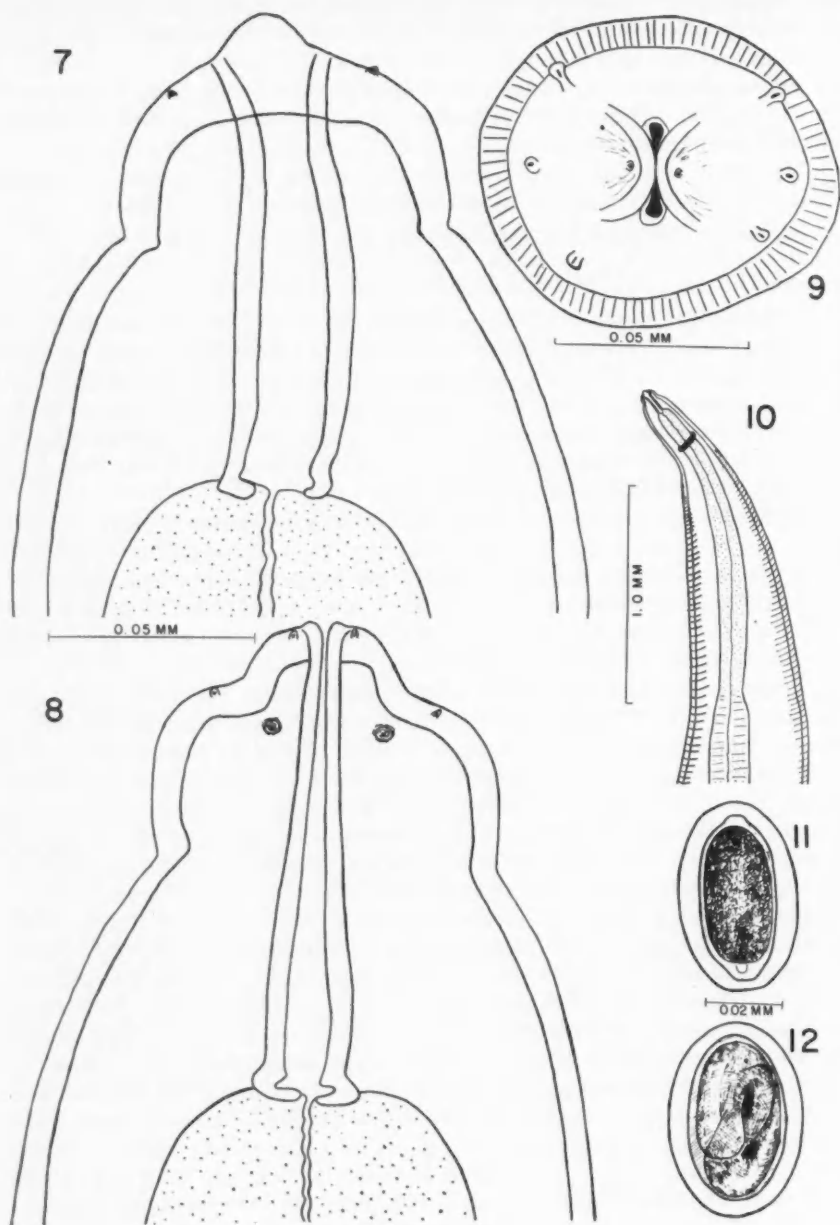
Genus *Crassicauda* Leiper and Atkinson, 1914

Crassicauda pacifica n. sp. (Fig. 7-12).

Twelve fragments of a large nematode, 50-93 cm. long by 5-7.5 mm. in diameter (after formalin fixation), were collected from the kidneys of a fin whale. All specimens proved to be parts of females. None of the examples possessed the tail portion. In eight females, including a 90-mm. portion, the anterior extremity was present. The remaining four females (one of 93 mm. length) lacked the anterior as well as the posterior extremity. Most of the worms contained ova with well developed embryos.

The heads of *Crassicauda* are buried in the tissue of the renculi, of which there are hundreds in the cetacean kidney, and are accompanied by dense connective tissue. The tails and greatest part of the body lie freely within the lumens of the branching reniferous tubules, often in intertwined masses containing up to 50 or more individuals. Complete worms are difficult to obtain as pointed out by Baylis (1922) and Rees (1953).

DESCRIPTION: This nematode is large, cylindrical and tapers abruptly at the anterior extremity. Females reach a maximum length of at least 93 mm., and a diameter of at least 7.5 mm. The cuticle is thick, $15\ \mu$ in the oesophageal region; the anterior 3 mm. is striated (the striations are $15\ \mu$ apart at the level of the beginning of the second part of the oesophagus), the remainder of the cuticle is smooth. The head is rounded and constricted 0.53 mm. posterior to the anterior extremity. The width of the head at the constriction is 0.09 mm., at the base of the buccal cavity 0.13 mm. and at the base of the oesophagus 3.5-4 mm. The mouth is a dorso-ventral slit, surrounded by two small lateral lips. There are 8 cephalic papillae; two small papillae antero-laterally on the lips (inner lateral papillae), two larger outer lateral papillae and four sub-median papillae. This arrangement of papillae is similar to that described by Baylis (1920, 1922) for *Crassicauda* spp. The buccal cavity is laterally compressed, $110\ \mu$ long by $28\ \mu$ in dorso-ventral width and $23\ \mu$ in latero-lateral width (including thickness of wall); the cuticular wall is $6.2\ \mu$ thick. The oesophagus is divided into two portions; the first part is glandular, 1.40-1.47 mm. long by 0.11-0.13 mm. wide; the second portion is partly glandular, partly muscular, usually coiled or folded back on itself several times at one point in its length, 19.25 mm. long by 0.17-0.25 mm. wide. The intestine, 0.63-0.73 mm. wide just posterior to its origin, diminishing to 0.44-0.45 mm. wide at a distance of 1.2-1.5 mm. from its origin, then increasing to a maximum width of about 1 mm., pursues a straight course. The



nerve ring is 0.33–0.34 mm. from the anterior extremity of the worm. The two ovaries, 1.4–1.8 mm. in diameter, reach to within 6.5–7.0 mm. of the cephalic end (in a fragment 63 mm. long by 6.8 mm. in diameter). Anteriorly the uteri are 0.35–0.45 mm. in diameter. The ova are thick-shelled, 50–54 μ by 34–36 μ . The above measurements were taken from two specimens, 53 mm. and 63 mm. long, both with maximum diameters of 6.8 mm.

The holotype specimen, a female, is to be deposited in the National Museum, Ottawa, Canada. Paratypes are in the collection of the Pacific Biological Station. The type host is the fin whale, *Balaenoptera physalus* (Linnaeus).

The family Crassicaudidae contains at present the genera *Crassicauda* and *Placentonema* Gubanov, 1951. The genus *Placentonema*, created by Gubanov (1951) for a new species, *P. gigantissima*, found in the placenta of a sperm whale differs from the genus *Crassicauda* chiefly in possessing two lateral caudal alae in the male and in having 32 uteri in the female. In the genus *Crassicauda*, caudal alae are absent and there are only two uteri. In the present material, although portions of the females containing the union of the uteri and vagina are missing, it has been possible to determine the presence of only two uteri. On the basis of this character and the location of the worms in the urino-genital system of the host, the present specimens are being allocated to the genus *Crassicauda* and the new species *C. pacifica* is created for their acceptance.

To date seven species of *Crassicauda* have been described, namely *C. crassicauda* (Creplin, 1829) (*Balaenoptera physalus*, *B. musculus*, *B. borealis*(?)), *Tursiops truncatus* (?); *C. boopis* Baylis, 1920, (*Megaptera nodosa*, *Ziphius cavirostris*(?)); *C. bennetti* Spaul, 1926 (*Hyperoodon glanifrons*); *C. fueleborni* (Hoepli and Hsu, 1929) (*Neomeris phocaenoides*); *C. giliakiana* Skrjabin and Andreewa, 1934 (*Delphinapterus leucas*); *C. magna* Johnston and Mawson, 1939 (*Kogia breviceps*); and *C. grampicola* Johnston and Mawson, 1941 (*Grampidelphis exilis*). The specimens of *C. boopis* from *Megaptera* were originally identified by Leiper and Atkinson (1914, 1915) with *Filaria crassicauda* Creplin, 1829. These authors proposed the new genus *Crassicauda* for this large nematode. Baylis (1920) re-examined these worms and created for them the new species *C. boopis*, clearly distinct from *Filaria crassicauda* (i.e. *Crassicauda crassicauda*). *Crassicauda fueleborni* was originally described as *Onchocerca fueleborni* by Hoepli and Hsu (in Hoepli, Hsu and Wu, 1929). Baylis (1932) transferred this species to *Crassicauda*. He also tentatively re-

FIGURES 7–12. *Crassicauda pacifica* n. sp.

(All illustrations are drawn with the aid of a camera lucida.)

7. Lateral view of cephalic extremity.
8. Ventral or dorsal view of cephalic extremity.
9. *En face* view of cephalic extremity.
10. Lateral view of anterior end.
- 11 and 12. Ova. Figure 11 represents an earlier stage in development than does 12.

ferred a single specimen (known only from the anterior extremity) from *Ziphius cavirostris*, to the species *C. boopis*. He had previously (Baylis, 1916b) placed this nematode in *C. crassicauda*. The fragments of *Crassicauda* recovered from the mammary glands of *Tursiops truncatus* were assigned to *C. crassicauda* by Joyeux and Baer (1931). Skrjabin and Andreewa (1934) doubted the correctness of the identification and preferred to refer to these specimens as *Crassicauda* sp.

The new species can be differentiated from other species of *Crassicauda* by the structure of the cephalic extremity in the species for which it has been described or by the size of the worm or character and size of the eggs in the species for which the head end has not been described.

The cephalic extremity is known in *C. crassicauda*, *C. giliakiana*, *C. fuelleborni*, *C. magna* and in *Crassicauda* sp. (?*boopis*) from *Ziphius cavirostris*. The presence of a pair of lateral lips in *C. pacifica* distinguishes this species from *C. crassicauda*, *Crassicauda* sp. of Baylis from *Ziphius* and *C. fuelleborni*, in which the lips are wanting. Lateral lips are also present in *C. giliakiana* and *C. magna*. The complete constriction of the head in the region of the buccal cavity conveniently serves to separate *C. pacifica* from *C. giliakiana*, *C. magna* and *C. fuelleborni* in which the head is not constricted from the rest of the body. According to Baylis' (1922) figures of *C. crassicauda*, the head end is constricted laterally but not dorso-ventrally. The new species also differs from these crassicaudids in the length and much narrower width of the buccal cavity, and in the greater maximum diameter of the body. Differences in the length and breadth of the two oesophageal regions, size of eggs, etc., are evident between *C. pacifica* and one or more of the species of which the anterior end is known. Table III compares measurements of the species of *Crassicauda* in which the anterior end has been described and figured.

In the species *C. boopis*, *C. bennetti*, *C. grampicola* and *Crassicauda* sp. of Joyeux and Baer, 1931, the anterior end has not been described. *Crassicauda pacifica*, with a diameter of 5-7.5 mm., is a much thicker worm than *C. boopis*, *C. grampicola* or *Crassicauda* sp. Joyeux and Baer. In *C. boopis*, posterior fragments of females up to 45 mm. long, with a maximum diameter of 4 mm., and males of 28 mm. long by 3 mm. in diameter have been described by Baylis (1920). Posterior fragments of males and females of *C. grampicola* up to 10 mm. long, with a maximum thickness of 1.5 mm. in females and 0.9 mm. in males, were described by Johnston and Mawson (1941). Joyeux and Baer's species of *Crassicauda* was only 1.5 mm. in diameter, although a posterior fragment 80 mm. long was recorded. The eggs of *C. boopis* ($50\ \mu \times 35-40\ \mu$) are similar in size to those of the new species ($50-54\ \mu \times 34-36\ \mu$), whereas those of *C. grampicola* ($40\ \mu \times 29\ \mu$) and *Crassicauda* sp. of Joyeux and Baer ($42\ \mu \times 27\ \mu$) are considerably smaller. *Crassicauda bennetti* approximates *C. pacifica* in size, posterior fragments of the former species, 46-100 mm. long by 6-8 mm. in diameter, having been recorded by Spaul (1926). However, the eggs of *C. pacifica* do not possess the conspicuous thickened belt of chitin round the middle region that is characteristic of fully developed eggs of *C. bennetti*. In addition

TABLE III. Comparison of measurements of *Crassicauda* spp. of which the anterior end is known. Data are from the original descriptions, except for *C. crassicauda*, in which some measurements are added from later publications. Measurements marked by an asterisk are taken from published figures. No measurements were given of the specimen of *Crassicauda* taken from *Ziphius cavirostris* and called *C. crassicauda* by Baylis (1916b); only an *en face* view of the head was figured.

	<i>C. crassicauda</i>	<i>C. giliakiana</i>	<i>C. fuelleborni</i>	<i>C. magna</i>	<i>C. pacifica</i>
Buccal cavity					
Length	Laterally compressed ♂ 180 μ ♀ 230 μ	Laterally compressed 162 μ	86 μ *	Laterally compressed ♀ 140 μ	Laterally compressed ♀ 110 μ
Width (latero-lateral)	♂ 54 μ *	35 μ *	...	♀ 80 μ *	♀ 23 μ
Depth (dorso-ventral)	♂ 74 μ *	55 μ	43 μ *	♀ 60 μ	♀ 28 μ
Thickness of wall	♂ 17 μ *	16 μ *	...	♀ 17 μ *	♀ 6.2 μ
Anterior oesophagus					
Length	♂ 1.85 mm. ♀ 1.95 mm.	...	1.0 mm.*	♀ 0.3 mm.	♀ 1.40-1.47 mm.
Width	♂ 0.11 mm. ♀ 0.16 mm.	Anteriorly 0.08 mm.*	0.07-0.09 mm.*	♀ 0.13 mm.*	♀ 0.11-0.13 mm.
Posterior oesophagus					
Length	♂ 25 mm. ♀ 31 mm.	...	...	♀ 1.5 mm.	♀ 19.25 mm.
Width	♂ 0.3-0.4 mm. ♀ 0.47-0.8 mm.	...	Anteriorly 0.17 mm.*	♀ 0.19 mm.*	♀ 0.17-0.25 mm.
Intestine—width anteriorly	...	...	...	♀ 0.55 mm.	♀ 0.63-0.73 mm.
Head—diameter at base of buccal cavity	♂ 0.35 mm.*	0.17 mm.*	0.17 mm.*	♀ 0.48-0.53 mm.	♀ 0.13 mm.
Nerve ring to anterior end	♂ 0.5 mm. ♀ 0.4 mm. (neck contracted)	...	0.26 mm.*	♀ 0.35 mm.	♀ 0.33-0.34 mm.
Body—maximum width	♂ 1.5 mm. ♀ 2.5 mm.	♂ 1.75 mm. ♀ 4 mm.	♂ 0.7 mm. ♀ 0.9 mm.	♀ 4 mm.	♀ 7.5 mm.
Ova					
Length	50 μ	54 μ	...	40-42 μ	50-54 μ
Width	35-40 μ	30 μ	...	23-28 μ	34-36 μ

the eggs of *C. bennetti* are larger than those of the new species, measuring $60-75\ \mu \times 30-35\ \mu$.

Balaenoptera physalus is the only host species from which two species of *Crassicauda* have been described. The two species are *C. pacifica* and *C. crassicauda*, which has been recorded from the fin whale in northern European seas, the Atlantic coast of South Africa and in the Antarctic at South Georgia and the Ross Sea area. In general, species of the genus *Crassicauda* appear to be host specific. *Crassicauda crassicauda* is the sole exception, having been definitely found in two closely related species of *Balaenoptera*, namely *B. physalus* and *B. musculus*. Baylis (1932) also lists *B. borealis* as a possible host, since crassicaudid worms were seen in the urino-genital system of this whale by Hamilton (in Baylis, 1916b). Unfortunately the worms were not collected. It has already been noted that the *C. crassicauda* individuals described by Joyeux and Baer (1931) probably do not belong to this species.

ACANTHOCEPHALA

Family POLYMORPHIDAE Meyer, 1931

Genus *Bolbosoma* Porta, 1908

Bolbosoma turbinella (Diesing, 1851) Porta, 1908

Ten males and 9 females of this acanthocephalid were recovered from the small intestine of the sei whale. The specimens were poorly fixed, resulting in extreme contraction of the body. However, in some specimens it was possible to observe that the lemnisci were extremely long and the arrangement of the hooks on the proboscis could be discerned in several individuals in which the proboscis was completely extended. On the basis of these two characters the specimens were assigned to the species *B. turbinella*.

The proboscis is 8-8.5 mm. long with a maximum breadth at the base of 0.45-0.50 mm. The hooks are arranged in 20-22 longitudinal rows with 7 to 8 hooks in each row. The anterior hooks are slender, about $50-60\ \mu$ long. The sub-apical, median and sub-basal hooks are sturdier, $60-80\ \mu$ long and the basal hooks slender, about $40-50\ \mu$ long. The sub-basal hooks are the sturdiest. The bases of the hooks are simple, backwardly directed and slightly longer than the claw, except in the basal row, where they are shorter.

The hooks on the bulb are heavy, covered with cuticle, measuring $50-160\ \mu$ in length, the posterior hooks being the longest.

The eggs (external shell) measure $168-184\ \mu$ long by $34-40\ \mu$ wide.

Bolbosoma turbinella has not been recorded previously from the North American coast. Porta (1909) described all species of *Bolbosoma*, including *B. turbinella*, reported up to the date of his publication. Harada (1931) described examples of *B. turbinella*, drawing particular attention to the nervous system, from the sei whale caught in the North Pacific near Japan. He pointed out the discrepancy between the number of longitudinal rows of hooks in his specimens (similar to the number observed in the present material) and the number re-

ported by Porta. A description, with figures, of *B. turbinella* is given also by Meyer (1933) in his excellent works on the Acanthocephala. Fukui and Morisita (1939) recorded this parasite from the sei whale caught in Japan, but Yamaguti (1939) believes their specimens probably belong to his new species *Bolbosoma nipponicum* Yamaguti, 1939, collected from *Balaenoptera rostrata* (= *acutorostrata*) in Japanese seas.

Bolbosoma turbinella is found in sei whales in the northern and southern hemispheres. Other hosts of this species are the blue whale (*Balaenoptera musculus*), the humpback whale and the bottlenose whale (*Hyperoodon rostratus*).

Two other species of *Bolbosoma*, namely *B. brevicolle* (Malm, 1867) and *B. balaenae* (Gmelin, 1790) (= *B. porrigens* (Rudolphi, 1814)) have been recorded from sei whales in other parts of the world.

Since parasitism of whales by helminths is undoubtedly linked with the feeding habits of the whales, a few words concerning the food of the whales in this locality seem to be in order.

Stomachs of fin and humpback whales have been found to contain euphausiids almost exclusively. Humpbacks occasionally contain herring, saury or squid. Sei whales usually contain copepods and less frequently euphausiids. Occasionally fishes have been found in their stomachs. The sperm whales feed chiefly on squid, rockfish, ragfish and occasionally on dogfish and skate. *Berardius* specimens have contained chiefly squid and rockfish. A brief note on the stomach contents of whales caught off the British Columbia coast has been published (Pike, 1950).

Whales are taken at the Coal Harbour whaling station only during the months of April to October. It is probable that the feeding habits of these whales, particularly baleen whales, are different during the winter months when the plankton production is at a minimum.

LIST OF THE PARASITES RECORDED, PRESENTED BY HOSTS

Balaenoptera borealis—sei whale

Trematoda:

Lecithodesmus spinosus n. sp.

†*Ogmogaster plicatus* (Creplin, 1829)

Nematoda:

Anisakis simplex (Rudolphi, 1809)

Acanthocephala:

†*Bolbosoma turbinella* (Diesing, 1851)

Balaenoptera physalus—fin whale

Trematoda:

*†*Lecithodesmus goliath* (van Beneden, 1858)

†*Ogmogaster plicatus* (Creplin, 1829)

Cestoda:

*†*Phyllobothrium delphini* (Bosc, 1802)

Nematoda:

†*Anisakis* sp.

Crassicauda pacifica n. sp.

*New host record.

†New record for the northeastern Pacific Ocean.

Megaptera nodosa—humpback whale

Nematoda:

†*Anisakis* sp.

Berardius bairdi—Baird's beaked whale

Nematoda:

**Anisakis simplex* (Rudolphi, 1809)

Physeter catodon—sperm whale

Cestoda:

†*Phyllobothrium delphini* (Bosc, 1802)

Nematoda:

Anisakis physeteris Baylis, 1923

†*Anisakis simplex* (Rudolphi, 1809)

*New host record.

†New record for the northeastern Pacific Ocean.

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Notes on the Morphology, Taxonomy and Synonymy of Several Species of Whale-lice (Cyamidae: Amphipoda)¹

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ABSTRACT

Maxilliped palps are present in adult *Cyamus ceti*, *C. scammoni* and *C. ovalis*; absent in adult *C. boopis*, *C. nodosus* and *C. gracilis*; their presence is variable in *C. erraticus* and *C. catodontis*. The genus *Paracyamus* is considered a direct synonym of *Cyamus*. *Neocyamus* n. gen. is created for the acceptance of *Cyamus physeteris* Pouchet. *Cyamus elongatus* Hiro is shown to be a synonym of *C. boopis* Lütken and *C. boopis* var. *physeteris* Pouchet is a synonym of *C. catodontis* Margolis. Further notes on the morphology of several species of cyamids are presented.

INTRODUCTION

THE FAMILY Cyamidae, at present, is considered as consisting of the genera *Cyamus* Latreille, 1796, *Paracyamus* Sars, 1895, *Platycyamus* Lütken, 1873, and *Isocyamus* Gervais and Beneden, 1859 (cf. Stephensen, 1942).

The genus *Paracyamus* was separated, by Sars (1895), from *Cyamus* solely on the basis of uni-articulate maxilliped palps in *Paracyamus* in contrast to the 5-segmented condition in *Cyamus*. The other genera differ fundamentally from the type genus, *Cyamus*, in several respects.

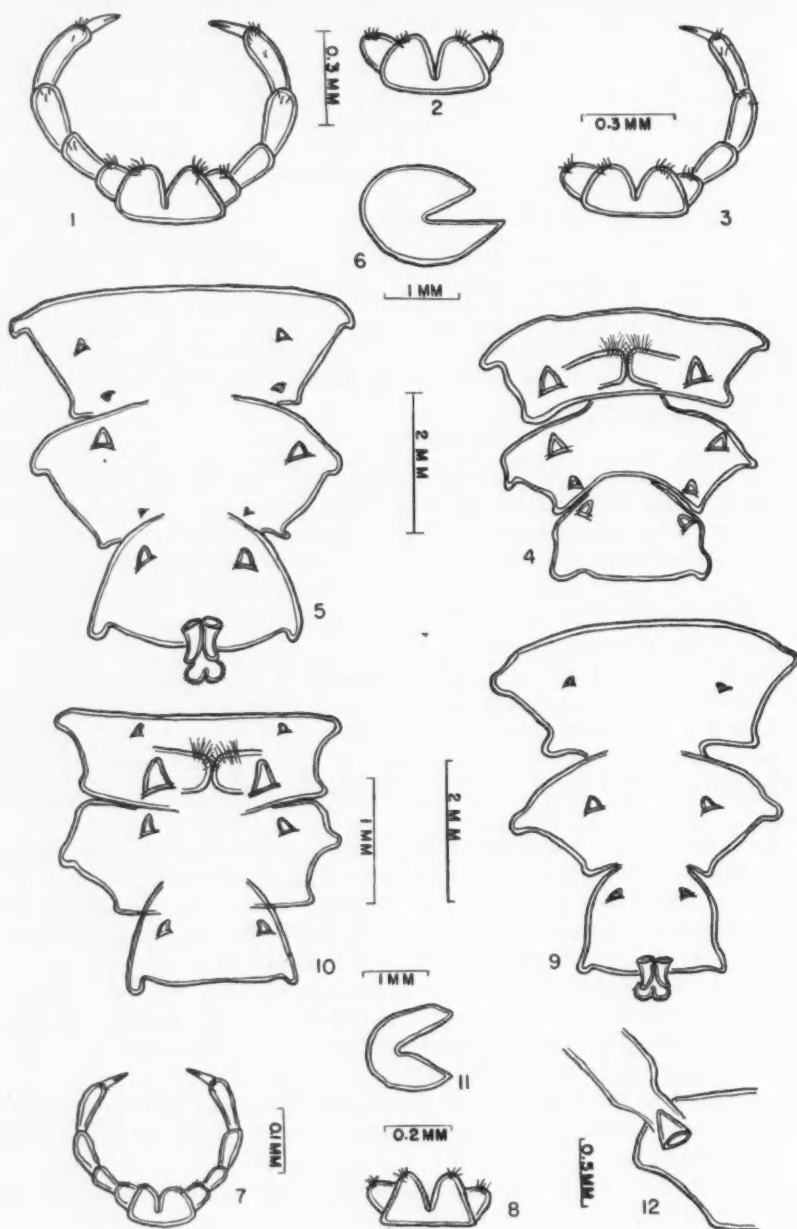
It will be shown here that the genus *Paracyamus* is not based on a morphological character that is sufficiently constant, at least in two species, to warrant its distinction from the genus *Cyamus* and that a new genus should be created for the acceptance of *Paracyamus physeteris* (Pouchet, 1888) Stephensen, 1942. The remainder of the species placed in *Paracyamus* should all be relegated to *Cyamus*.

From the studies that were carried out it became apparent that detailed descriptions of the mouth parts of most cyamids are not available, although the species are mostly well defined. As the structure of the oral appendages has yielded important information concerning the relationship of species, increased knowledge of the mouth parts would certainly lead to a more stable and satisfactory classification. Preliminary observations on nine species of whale-lice have resulted in the aforementioned modifications in the generic classification. Further changes in the classification might arise in the future from more extensive studies of the buccal appendages.

In addition to the brief study of the mouth parts, some observations, that have led to the creation of new synonyms, have been made on other morphological characters.

All specimens were studied, after clearing in lactophenol, under 100× or 200× magnification.

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Cyamus erraticus Roussel de Vauzème, 1834. (Fig. 1-6)

Paracyamus erraticus (R. de Vauzème, 1834) Barnard, 1932.

Cyamus erraticus was created by Roussel de Vauzème (1834) for one of the whale-lice species which he found parasitizing the southern right whale, *Balaena australis*, from South Atlantic waters. Since then the species has been completely or partially redescribed by Krøyer (1843), Lütken (1873), Chevreux (1913), Barnard (1932), Iwasa (1934), Sawaya (1938) and Stephensen (1942). It has been found on the black right whale, *Balaena glacialis* (= *biscayensis*), in the North Atlantic and North Pacific as well as *B. australis* in the South Atlantic and Antarctic. (Some authors believe that *B. glacialis* and *B. australis* are synonymous.)

Roussel de Vauzème, Krøyer, Lütken and Sawaya did not describe the maxilliped palps. Chevreux, Barnard and Stephensen described them as uni-articulate in adults, but 5-segmented in juveniles. Iwasa described and illustrated fully developed maxilliped palps in adults. He considered the palps to be 4-segmented and the maxillipeds 2-segmented, in contrast to the 5-segmented palp and uni-articulate maxilliped of earlier authors. This interpretation of structure was followed by Hiro (1938) and Margolis (1954a).

Sars (1895) had created *Paracyamus* for *C. boopis* Lütken, 1870. He suggested that *C. erraticus* probably belonged in this new genus.

Barnard and Stephensen placed the species in *Paracyamus*, but Chevreux preferred to retain it in the genus *Cyamus* because of the fully developed maxilliped palps in juveniles. Iwasa, finding fully developed maxilliped palps in adults, retained *erraticus* in *Cyamus*, as did Sawaya, although he did not describe the maxilliped palps.

As different authors are at variance in reporting the presence or absence of maxilliped palps in adults, attention was directed to this structure in *C. erraticus* as well as in several other species.

A series of specimens of *C. erraticus*, obtained from the black right whale (*B. glacialis*) off the Pacific coast of Canada, were turned over to me by Mr. G. C. Pike of this station. Of 37 adult males (9-13.2 mm. long), 18 possessed both maxilliped palps, 9 had 1 complete palp and 1 to 3 segments of the other palp, 5 had one complete palp and the other one entirely lacking, 3 had only 1 to 3 segments of one palp, and 2 lacked both maxilliped palps in their entirety. Fifty-

FIGURES 1-12. *Cyamus erraticus* and *C. boopis*

C. erraticus. 1. Maxillipeds and fully developed maxilliped palps of ovigerous female 11.5 mm. long. 2. Maxillipeds without palps of 11-mm.-long female carrying embryos. 3. Maxillipeds with only one complete palp of 10-mm.-long male. 4. Female, ovigerous, 11.5 mm. long. Ventral view of pereon segments 5-7. 5. Male, 13 mm. long. Ventral view of pereon segments 5-7. 6. Accessory gill of 13-mm.-long male, left on 4th segment. Ventral view.

C. boopis. 7. Maxillipeds and fully developed palps of juvenile 2.5 mm. long. 8. Maxillipeds without palps of ovigerous female 9.5 mm. long. 9. Male, 14 mm. long. Ventral view of pereon segments 5-7. 10. Female, immature, 6.8 mm. long. Ventral view of pereon segments 5-7. 11. Accessory gill of 14-mm.-long male, left on 4th segment. Ventral view. 12. Spine-like accessory gill on 4th segment, right side, of 6.5-mm.-long immature male. Ventral view.

one adult females (7.2–10.5 mm. long) were examined from this collection. Thirty-one had both palps, 4 had 1 complete palp and 1 to 3 segments of the other palp, 12 possessed 1 complete palp only, and 2 lacked both palps.

Specimens of *C. erraticus* collected from *B. australis* in the South Atlantic and Antarctic and presumably from *B. glacialis* (= *biscayensis*) in Arctic-Atlantic seas were lent to me by Dr. Torben Wolff of the Zoological Museum of Copenhagen. Some of the specimens had been identified by Krauss, Lütken and Sars. Five adult males (15–16 mm. long) and 1 adult female (9 mm. long) were from the Arctic-Atlantic and 7 adult males (9–16 mm. long) and 5 adult females (8–9.1 mm. long) were from the South Atlantic and Antarctic. Of the Arctic-Atlantic male specimens, 2 had both maxilliped palps, 2 had only 1 palp and 1 lacked both palps; the female lacked both palps. Of the South Atlantic and Antarctic males, 2 possessed both palps, 1 had only 1 palp and 4 lacked both palps; of the females, 3 had both palps and 2 lacked them.

Three adult males (13.5–14.5 mm. long) and 2 adult females (9 and 10.5 mm. long) of this species were obtained from Dr. K. H. Barnard of the South African Museum. The specimens, presumably, were collected from *B. australis* off South Africa. Only 1 male possessed 1 complete maxilliped palp. The others were without both palps.

From this study it is apparent that the presence or absence of maxilliped palps (Fig. 1–3) cannot be considered of taxonomic importance in *Cyamus erraticus*.

One other character of *C. erraticus* not similarly described by all authors is the number of ventral spines on the pereopod segments of the male. All authors agree that in the female there are 1 pair of spines on segment 5, 2 pairs on segment 6 and 1 pair on segment 7. All female specimens that I have examined (lengths 4–10.5 mm.) displayed this arrangement of spines (Fig. 4).

Lütken (1873) and Stephensen (1942) described the arrangement of spines in the male as similar to that in the female. Barnard (1932) mentioned only 1 pair of spines on each of segments 5, 6 and 7. Iwasa (1934) and Sawaya (1938) stated that there are 2 pairs of spines on each of segments 5, 6 and 7. These authors consider the pair of large conical processes on the posterior margin of segment 7 as a pair of spines.

In all the male specimens examined, ranging in length from 2.5-mm. juveniles to 16-mm. adults, the spination is as described by Iwasa and Sawaya (Fig. 5). The posterior pair of spines on segment 5 are the smallest. The second pair on segment 6 are quite small, too. This probably accounts for the lack of their description by some authors.

Cyamus boopis Lütken, 1870, (Fig. 7–12)

Cyamus suffusus Dall, 1872.

Cyamus elongatus Hiro, 1938; new synonymy.

Paracyamus boopis (Lütken, 1870) Sars, 1895.

I recorded this species, as *P. boopis*, from the British Columbia coast in a previous paper (Margolis, 1954a), but did not comment on the morphology.

Lütken (1873), Sars (1895), Barnard (1932 and others described 1 pair

of spines on the ventral surface of each of pereon segments 5, 6 and 7 of the female and 1 pair on each of segments 6 and 7 (plus the large pair of conical processes posteriorly on segment 7) on the male.

Re-examination of specimens from the British Columbia coast, from the North Atlantic (obtained from the Copenhagen Museum) and from South Africa (obtained from the South African Museum), revealed the spination to be somewhat different. In the male there is 1 pair of spines on each of segments 5, 6 and 7, and the large conical processes posteriorly on segment 7 (Fig. 9). The pair of spines on segment 5 are small and hence, apparently, have been overlooked by earlier authors. In the female there are 2 pairs of spines on segment 5 and 1 pair on each of segments 6 and 7 (Fig. 10). One pair on segment 5 are large and lie postero-lateral to the genital flaps. This is the pair illustrated by former workers. The second pair occur antero-lateral to the genital flaps, are quite small and usually not visible in mature females, as they are covered by the posterior margins of the oostegites. They can only be seen in mature females if the oostegites are removed and even then only in well-cleared specimens. In juvenile females, where the oostegites are incompletely developed, both pairs of spines are readily seen in cleared specimens. In very young females, up to about 4 mm. long, the posterior pair of spines on segment 5 are usually so feebly developed that they are barely, if at all, visible.

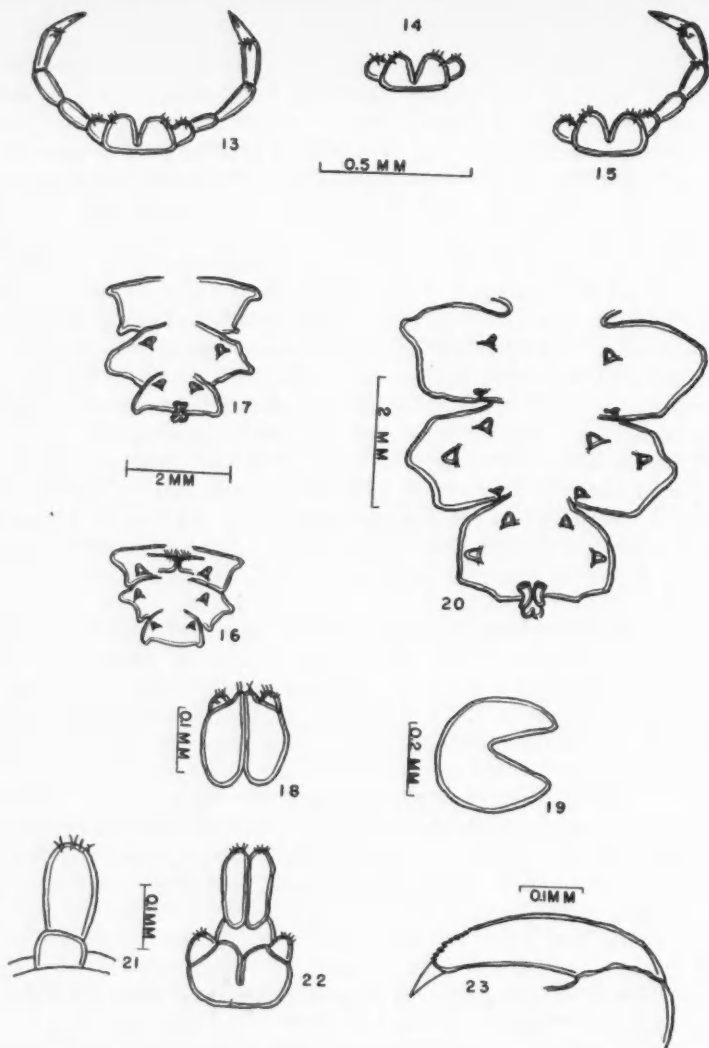
Of approximately 100 adult males and females from British Columbia, 40 adults from the North Atlantic and 12 adults from the South Atlantic, none possessed maxilliped palps (Fig. 8). Juveniles up to 3 mm. long always carried fully developed palps (Fig. 7). The palps apparently disappear between the lengths of 3 to 5.5 mm. Occasionally part of the palps was seen in juveniles up to 6.5 mm. long.

Cyamus elongatus Hiro, 1938, was described from 7 specimens, lengths 2.75-6.75 mm., recovered from the barnacle *Coronula diadema* which was believed to have been taken from a humpback whale in Japanese Seas. The species was said to be similar to *C. boopis* but differed mainly in the following respects:

- (1) shape of the segments,
- (2) shorter gills,
- (3) lack of accessory gills in the male,
- (4) presence of a spine at the base of the gills on the ventral surface of pereon segments 3 and 4.

A comparison of juvenile *C. boopis* with Hiro's figures and description, leads to the conclusion that *C. elongatus* was based on juvenile *C. boopis* and accordingly is a direct synonym of the latter species.

The shape of the segments as figured by Hiro (1938) is identical with that found in juvenile *C. boopis*. Short gills are also characteristic of juvenile stages of *C. boopis*. In specimens less than 5 mm. long the gills are shorter than pereon segments 2 to 4, inclusive. Specimens between 6 and 7 mm. long have gills less than the length of pereon segments 2 to 5, inclusive. The spines at the base of the gills in the male, as described by Hiro, are in reality the developing accessory gills. These structures in the male of *C. boopis* are single and spine-like in specimens up to about 7 mm. long (Fig. 12). In larger specimens they



FIGURES 13-23. *Cyamus catodontis*, *C. ceti* and *Neocyamus physeteris*

C. catodontis. 13. Maxillipeds and fully developed palps of 6-mm.-long male. 14. Maxillipeds without palps of 5.9-mm.-long female carrying embryos. 15. Maxillipeds with only 1 complete palp of 4.2-mm.-long immature female. 16. Female, 5.9 mm. long. Ventral view of peraeon segments 5-7. 17. Male, 7 mm. long. Ventral view of peraeon segments 5-7. 18. Maxillae-2 of 7.2-mm.-long male. 19. Accessory gill of 7.2-mm.-long male, left on 4th segment. Ventral view.

C. ceti. 20. Male, 10 mm. long. Ventral view of peraeon segments 5-7.

N. physeteris. 21. Antenna-2 of 9-mm.-long male. 22. Maxillipeds and maxillae-2 of ovigerous female 7 mm. long. 23. Dactylus and unguis of ovigerous female 7 mm. long.

begin to take on the bifurcated condition characteristic of adults. The two arms of each accessory gill do not become approximately equal in length until the animal reaches a length of about 9.5 to 10 mm. (Fig. 11).

In females less than 5 mm. long, the oostegites are very rudimentary and are not fully developed until the body is about 7 mm. long. The smallest specimen bearing eggs was 7.2 mm. long.

Six males (8.5–12 mm. long) and 2 females (5.7 and 6.8 mm. long), obtained from the Copenhagen Museum, carried the label *Cyamus erraticus*. The specimens were collected from a humpback whale, Hokkaido, Japan, and were identified by M. Iwasa. Examination of these specimens led me to place them with *C. boopis*. The maxilliped palps were absent in all individuals, the spination was that characteristic of *C. boopis* as described here and the branches of the accessory gills in fully developed males were of equal length. The body was also more slender and the gills shorter than *C. erraticus* of similar length.

It thus appears that there is only one species of cyamid parasitic on the humpback whale of the North Pacific.

Cyamus boopis is very closely related to *C. erraticus*. Besides differing by the consistent lack of maxilliped palps in adults, *C. boopis* can be differentiated from *C. erraticus* by the arrangement of the ventral spines of the peraeon segments. There is 1 pair on each of segments 5, 6 and 7 of the male and 2 pairs on segment 5 and 1 pair on each of segments 6 and 7 of the female of *C. boopis*. In *C. erraticus* males there are 2 pairs on each of segments 5 and 6 and 1 pair on segment 7 and in females there is 1 pair on each of segments 5 and 7 and 2 pairs on segment 6. The gills of *C. boopis* are somewhat shorter than those of *C. erraticus* and the branches of the accessory gills of males are about equal in length in fully mature *C. boopis*, whereas the posterior branch is usually definitely longer than the anterior branch in *C. erraticus* (Fig. 6). *Cyamus boopis* is also slightly slenderer than *C. erraticus*. The inner and outer incisor processes of the left mandible of *C. boopis* each bear 5 teeth, whereas in *C. erraticus* the inner process carries only 4 teeth.

Cyamus catodontis Margolis, 1954. (Fig. 13–19)

Cyamus boopis Lütken, var. *physeteris* Pouchet, 1892; new synonymy.

The species *C. catodontis* was created for eight specimens taken from a sperm whale (Margolis, 1954a). Since the species was described I have obtained several specimens from the Copenhagen Museum, labeled *Cyamus boopis* Lütken var. *physeteris* Pouchet. These specimens had been set to *C. F. Lütken* of Copenhagen by G. Pouchet and F. A. Chaves and had been collected from sperm whales taken near the Azores. After examination of these specimens it became apparent that they are identical with *C. catodontis*. Since the trivial names *boopis* and *physeteris* are pre-occupied for other cyamids, the specific name *C. catodontis* must be maintained.

In establishing *Cyamus boopis* var. *physeteris*, Pouchet (1892) pointed out that the specimens were much smaller (males 6.5 mm. long and females 5 mm. long) than *C. boopis* but failed to recognize any other differences. Lütken (1893) in re-examining some of the specimens did not note any further differ-

ences from *C. boopis*. These authors did not offer descriptions or illustrations of the specimens, beyond stating that they were similar to *C. boopis*, but smaller. There is no doubt that this species, now known as *C. catodontis*, is distinct from *C. boopis*, and its host, in the Atlantic and Pacific Oceans, is the sperm whale.

The specimens taken from a sperm whale near South Africa, and identified with *C. boopis* by Barnard (1932), possibly are referable to *C. catodontis*.

A re-examination of all specimens available to me indicated that some further details should be added to the description. The main point to comment on is that, as in *C. erraticus*, all adult specimens do not possess fully developed maxilliped palps (Fig. 13-15), such as was indicated in the specimens upon which the species was based. Of six specimens from the Copenhagen collection, 2 males (4.4 and 6 mm. long) and 2 females (5.5 and 5.6 mm. long) possessed both entire palps, 1 female (4.2 mm. long) had only 1 complete palp and the other female (5.9 mm. long) lacked both palps entirely. The 4.2-mm.-long female was not quite mature, judging by the incompleteness of the oostegites. The other females were carrying embryos. The antero-median margins of the genital flaps bear many bristles (Fig. 17), a character which is apparently present in all cyamids. The inner lobes of the 2nd maxillae bear two closely approximating bristles, not one as indicated in the original description (Fig. 18) and the inner and outer incisor processes of the left mandible bear 5 and 4 or 5 teeth, respectively. The original statement of 3 teeth in each incisor is incorrect.

At the time *C. catodontis* was described it was not critically compared with *C. erraticus*, *C. boopis*, *C. nodosus* or *C. gracilis*, since these species had been placed in the genus *Paracyamus* (cf. Stephensen, 1942), which was supposed to be quite distinct from *Cyamus*. As it is being pointed out that *Paracyamus* is an invalid genus it will be necessary to differentiate *C. catodontis* from these four species in order to establish its validity.

Cyamus gracilis and *C. nodosus* differ radically from *C. catodontis*. On the other hand, *C. erraticus*, *C. boopis* and *C. catodontis* are very closely related. Accordingly, it will be necessary to compare *erraticus* and *boopis* with *catodontis* in detail, but not so with *gracilis* and *nodosus*.

Cyamus gracilis is distinguished from *C. catodontis* by the shape of the body and head, by possessing deep lateral notches on segments 5 to 7, by the short gills and very short accessory gills and by the lack of spines on the ventral surface of the peraeon segments. *Cyamus nodosus* is a unique species by virtue of the grooves on the dorsal surface of the peraeon segments, particularly segments 3 and 4.

Cyamus catodontis differs from *C. erraticus* as follows:

(1) Much smaller size. *C. catodontis* males and females range up to 7.2 mm. and 5.9 mm. long, respectively. *Cyamus erraticus* males and females are up to 16 mm. and 12 mm. long, respectively. *Cyamus catodontis* females mature at a length of 4.5 mm. or less and are carrying embryos at 4.8 mm. Females of *C. erraticus* are not mature until they are 7 mm. and occasionally 8 mm. long. Oostegites of females 4-4.5 mm. long are very rudimentary and are still very incomplete in females 6 mm. long.

(2) Spines on peraeon segments. In *C. catodontis* the male has 1 pair of spines on each

of segments 6 and 7 (plus the large pair of conical processes on segment 7) and the female has 1 pair on each of segments 5, 6 and 7 (Fig. 16 and 17). Males of *C. erraticus* have 2 pairs on each of segments 5 and 6, and 1 pair of segment 7 (plus the posterior conical processes), and females of this species have 1 pair on each of segments 5 and 7 and 2 pairs on segment 6.

(3) Length of arms of the accessory gills in fully grown males. In *C. catodontis* they are equal (Fig. 19), whereas the posterior arm is decidedly longer in *C. erraticus*.

(4) The length of the gills compared to the length of the body is somewhat greater in *C. erraticus*.

(5) The inner incisor process of the left mandible bears 5 teeth in *C. catodontis* and 4 in *C. erraticus*.

Cyamus catodontis differs from *C. boopis* as follows:

(1) Maxilliped palps are possessed by most specimens of *catodontis* but are invariably absent in adult *boopis*.

(2) Smaller size. Males and females of *C. catodontis* are up to 7.2 mm. and 5.9 mm. long, respectively. Males and females of *C. boopis* are up to 14.5 mm. and 10.5 mm. long, respectively. Females of *C. boopis* have incompletely developed oostegites (i.e. they are immature) up to 6.7 mm. long. The smallest egg-bearing female that I examined was 7.2 mm. long. Females of *C. catodontis* are mature at a length of at least 4.5 mm. At similar body lengths as *C. catodontis*, the gills of *C. boopis* are much shorter. In *C. boopis* males of length equivalent to mature male *catodontis*, the accessory gills are still single and spine-like.

(3) Ventral spines on pereon segments. In *C. catodontis* males there is 1 pair of spines on each of segments 6 and 7 (plus the posterior conical processes on segment 7). In the female there is 1 pair of spines on each of segments 5, 6 and 7. Males of *C. boopis* have 1 pair on each of segments 5, 6 and 7 (plus the conical processes on segment 7), and females have 2 pairs on segment 5 and 1 pair on each of segments 6 and 7.

Cyamus scammoni Dall, 1872

Since recording this species from British Columbia (Margolis, 1954a) I have obtained another lot of specimens, collected by Mr. G. C. Pike, from the gray whale, *Eschrichtius glaucus*, April 1953. Some of these specimens are the largest recorded for the species. Males ranged up to 27 mm. long and females up to 17 mm. long. Lütken (1887), describing specimens obtained from W. H. Dall of California, gave the maximum length of males as 16 mm. and that of females as 12 mm.

The light purple coloration of the dorsum of the pereon segments, particularly segments 3 and 4, of adults is very characteristic of this species. It is also exceedingly larger than any other species. The size, colour and spirally coiled, double branchiae make *C. scammoni* a very distinct species.

All specimens examined possessed fully developed maxilliped palps.

Cyamus ovalis Roussel de Vauzème, 1834

This species was identified from a miscellaneous collection of whale-lice sent from the Copenhagen Museum. They were collected July 28, 1903, by the German South Polar Expedition of 1901-1903 from a *B. australis* caught near Simons-town, South Africa.

This species is readily recognizable by the straight double gills on segments 3 and 4.

All adults possessed fully developed maxilliped palps.

Cyamus gracilis Roussel de Vauzème, 1834*Paracyamus gracilis* (R. de Vauzème, 1834) Barnard, 1932.

Specimens of this species were identified from the Copenhagen collection. They had been collected near Patagonia and the host was probably *B. australis*.

Adult specimens lacked maxilliped palps.

Cyamus nodosus Lütken, 1860*Paracyamus nodosus* (Lütken, 1860) Stephensen, 1942.

Many specimens of this species were present in unidentified material obtained from the Copenhagen Museum. Several lots had been collected from the narwhal (*Monodon monoceros*) caught in the vicinity of Greenland. About 50 specimens had been taken from a beluga (*Delphinapterus leucas*) captured near Greenland. This new host record has been commented on previously (Margolis, 1954b).

All adult specimens lacked maxilliped palps.

Cyamus ceti (Linné, 1754) Lamarck, 1801. (Fig. 20)*Cyamus mysticeti* Lütken, 1870.*Cyamus mysticeti* Dall, 1872.

Twenty-eight specimens (5 adults of each sex and 18 juveniles) were obtained from the Copenhagen Museum. They had been collected from the bowhead whale, *Balaena mysticetus*, of the eastern Arctic during the years 1840(?) to 1889 and had all been examined by C. F. Lütken.

According to Lütken (1873) and Stephensen (1942) this species, the type of the genus *Cyamus*, occurs only on the bowhead whale, an inhabitant of Arctic regions only. Lütken reviewed the literature on this species and replaced Linné's trivial name, *ceti*, by *mysticeti* since *ceti* had been used for a variety of species. However, the original *ceti* was that species which is found on the bowhead whale and must remain as the valid name.

Dall (1872) described this species, which he believed to be new, as *Cyamus mysticeti*. The host was the bowhead whale caught in the Bering Strait. Lütken (1887) found these specimens to be identical with his *mysticeti* (i.e. *ceti*) of the eastern Arctic.

Lütken (1873) illustrated 1 pair of spines on pereopod segment 5, 3 pairs on segment 6 and 2 pairs on segment 7 of the male. Re-examination of his specimens indicated that, as in the female, there are 2 pairs of spines on segment 5 (Fig. 20), of which the anterior are the larger.

All specimens possessed fully developed maxilliped palps.

The genera *Paracyamus* and *Cyamus*

Species of the genera *Paracyamus* and *Cyamus* have been distinguished solely on the basis of the absence of maxilliped palps in adults of the former genus (Sars, 1895).

Of the species examined, *boopis*, *gracilis* and *nodosus* would appear to belong

to *Paracyamus*, whereas *scammoni*, *ovalis* and *ceti* fit into *Cyamus*. The species *erraticus* and *catodontis*, however, seem to be intermediate between *Cyamus* and *Paracyamus*, since the maxilliped palps may or may not be present. This character is not of taxonomic value in these two species, and hence, in itself, cannot be considered as a generic diagnostic character. Since there do not appear to be any other morphological features common to all species formerly placed in *Paracyamus*, which are not possessed by those placed in *Cyamus*, I am considering *Paracyamus* as a synonym of *Cyamus*.

Neocyamus new genus

DEFINITION: With characters of the family. Gnathopods 1 and 2 equal. Peraeon segment 1 coalesced with the head. Antenna 2, 2-jointed. Maxilla 2 without outer lobes. Maxilliped, 2-segmented. Maxilliped palps lacking in adults, 4-jointed in juveniles. Dactylus and unguis of gnathopod 1 distinct. Branchiae on peraeon segments 3 and 4 fasciculate. Accessory gills in male absent.

TYPE SPECIES: *Neocyamus physeteris* (Pouchet, 1888).

Neocyamus physeteris (Pouchet, 1888). (Fig. 21-23)

Cyamus physeteris Pouchet, 1888.

Cyamus fascicularis Verrill, 1892.

Paracyamus physeteris (Pouchet, 1888) Stephensen, 1942.

Pouchet (1888, 1892) described this species from material collected from the sperm whale caught near the Azores. Lütken (1893) redescribed the species from material obtained from Pouchet and G. A. Chaves from the same locality. Verrill (1892), apparently unaware of Pouchet's work, described the species, as *C. fascicularis*, from specimens obtained from the sperm whale near Bermuda. Stephensen (1942) placed the species in the genus *Paracyamus*, on the basis of absence of maxilliped palps.

A re-study of all specimens² (7 adult females, 3 adult males, 5 juveniles and many embryos from the marsupium of females) of this species contained in the collection of the Copenhagen Museum revealed certain characters that do not conform to the generic diagnosis of *Cyamus*.

Barnard (1932) defined *Cyamus* as follows: Gnathopods 1 and 2 unequal. Antenna 2, 4-jointed. Maxilla 2 with outer lobes. Maxilliped palp fully developed in adult. Dactylus and unguis of gnathopod 1 evenly tapering, the latter not distinct. Branchiae on segments 3 and 4, single or double, or fasciculate, straight or spirally coiled. In the light of the findings of the present investigation this definition should be modified to "maxilliped 2-segmented. Maxilliped palps absent or up to 4-segmented. Gills single or double, straight or coiled on segments 3 and 4. Accessory gills in male present".

The species *N. physeteris* differs from all species of *Cyamus* in the following five characters:

²The specimens were collected from the sperm whale near the Azores by Pouchet in 1891 and by Chaves in 1893 and 1900. One vial, labeled "*Cyamus boopis* Ltk. var. *physeteris* Pouch. (Ltk. det.)", contained both *N. physeteris* and *C. catodontis*.

- (1) antenna 2, 2-jointed (Fig. 21),
- (2) maxilla 2 without outer lobe (Fig. 22),
- (3) dactylus and unguis of gnathopod 1 distinct (Fig. 23),
- (4) accessory gills in male lacking,
- (5) gills fasciculate.

It seems justified, on the strength of the above characters, to remove *physeteris* from the genus *Cyamus*. Of the remaining two genera, *Isocyamus* and *Platycyamus*, *N. physeteris* most closely resembles *Isocyamus*. This genus, of which the type and only species is *I. delphini* Guérin-Ménéville, 1836, was defined by Barnard (1932) as follows: "Gnathopods 1 and 2 unequal. Antenna 2 reduced to three joints. Maxilla 2 without outer lobes. Maxilliped, lobes fused, without trace of palp. Unguis of gnathopod 1 distinct from the dactylus. Branchiae single on both segments 3 and 4". "Accessory gills in males present" should be added to the definition.

Pouchet's *physeteris* differs from *Isocyamus* as follows:

- (1) Antenna 2, 2-jointed,
- (2) Maxilliped 2-segmented (Fig. 22),
- (3) Accessory gills in male lacking,
- (4) Gills fasciculate.

ACKNOWLEDGMENTS

I wish to express my gratitude to Dr. Torben Wolff of the University Zoological Museum, Copenhagen, for the loan and donation of several species of cyamids. Thanks also are due Dr. K. H. Barnard of the South African Museum, Capetown, for the gift of several specimens of *C. boopis* and *C. erraticus*. The specimens of whale-lice from the British Columbia coast, upon which part of this study was based, were collected by Mr. G. C. Pike of this Station.

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The Resistance to Salt Water Corrosion of Various Types of Metal Wire Used in the Tagging of Flatfish¹

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ABSTRACT

Observations on the metal used as pins for Petersen-type tags on *Parophrys vetulus* showed manufactured nickel pins to be most subject to corrosion or wear, with pins of silver wire, nickel and stainless steel wire successively less liable. Tagging wounds were worst with nickel pins and least with stainless steel wire. A correction factor of approximately 1.7 for each year the tag is out is necessary to bring results with nickel pins on a par with those of stainless steel wire.

INTRODUCTION

ESTIMATES of the rates of mortality in a fish stock may be obtained from a study of the pattern of tag recoveries from year to year. This type of investigation demands that the tag in use be a permanent one, in the sense that it remains attached until the fish either is recaptured or dies from natural causes.

In the investigation of salt water populations this requirement has been difficult to meet, in view of the fact that tagging pins made of nickel (which until recently were widely used in marine studies) are subject to corrosion and hence to breakage and loss. Some indication of the seriousness of this problem has been shown recently by California workers (Calhoun *et al.*, 1951).

The Groundfish Investigation of the Pacific Biological Station has been conducting further studies on the subject of corrosion. These have a two-fold purpose: (1) to determine which metals are least subject to corrosion and most practical for future tagging experiments and (2) to determine a factor for the corrosion rate of nickel which can be used to correct the recovery data on past experiments in which that type of metal was used for the attachment of tags.

This report contains further information on the rate of corrosion in nickel pins and also a comparison of the performance of various other types of wire, based on tag recapture data. A preliminary attempt has been made to estimate the rate of breakage and loss in nickel pins.

The writers wish to acknowledge assistance of various staff members of the Pacific Biological Station, in particular Mr. W. E. Barraclough who helped with tagging operations and Mr. R. M. Wilson who handled tag recoveries at the port of Vancouver.

CORROSION OF NICKEL WIRE

Petersen-type disc tags attached with manufactured nickel pins have been used in tagging experiments with two flatfish species in several areas off the Brit-

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ish Columbia coast. Populations of lemon sole (*Parophrys vetulus*) have been tagged in the Strait of Georgia and in Hecate Strait. Populations of brill (*Eopsetta jordani*) have been tagged in waters off the west coast of Vancouver Island.

Tags recovered from the three areas were examined for condition and recorded according to the number of months they had been at large. In recording the condition of the tagging wire or pin three categories were used: (1) *no corrosion*—pins which showed no evidence under microscopic examination of pitting or hollowing, (2) *slight corrosion*—pins which showed signs of corrosion but little or no weakening when tested with pliers, (3) *severe corrosion*—pins which showed pronounced hollowing, and obvious weakness when tested with pliers. Cases of severe corrosion were not always readily detectable in superficial examination. Pins which on the surface appeared to be perfectly sound (Fig. 1A) were often found to be severely weakened or even hollow within when tested (Fig. 1B). More obvious examples of splitting and hollowing are shown in Figures 1C, 1D and 1E.

Figure 2 (data from Table I) shows the percentage of tag pins unaffected by corrosion at various intervals during a 42-month recovery period. These estimates are maximal, since losses through breakage of affected pins would cause the apparent percentage of unaffected pins to be higher than actual. A rapid decline occurred within the first 18 months to 16%. Between the 19th and 42nd

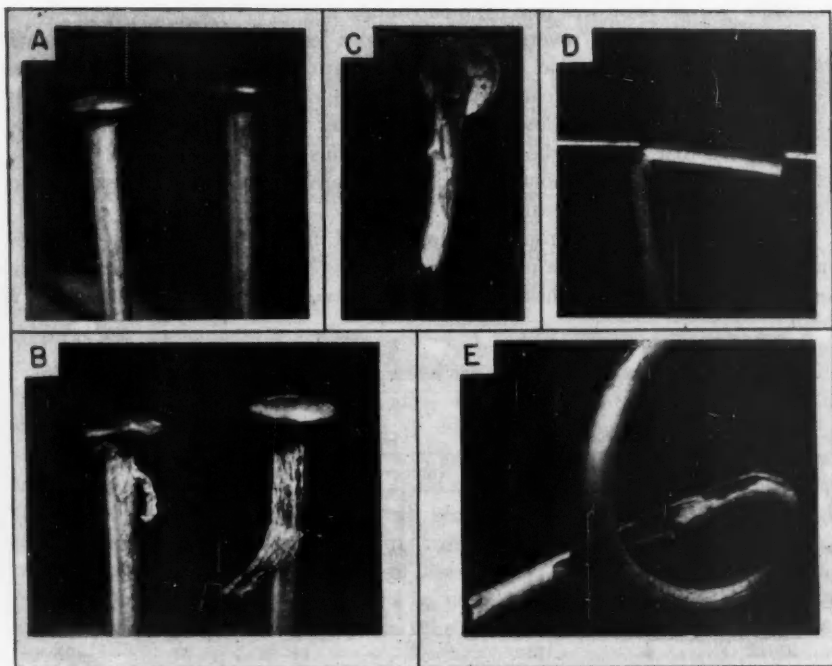


FIGURE 1. Examples of corrosion in nickel tagging pins (see text for details).

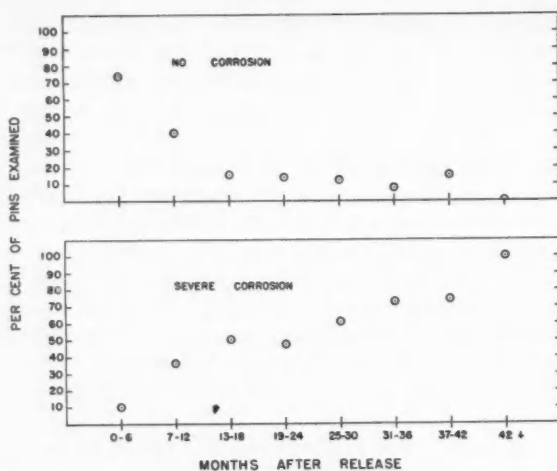


FIGURE 2. The condition of nickel tagging pins at six-month recapture intervals. Estimates of "no corrosion" are maximal while those of "severe corrosion" are minimal.

months the numbers unaffected fluctuated between 8 and 15%. After the 42nd month, however, none was free from corrosion.

The percentage of "severely" corroded pins for the same intervals is shown in Figure 2 also. At the end of 18 months approximately 50% of the recoveries could be assigned to that category. After 18 months the incidence of severely corroded pins rose steadily and reached 100% after the 42nd month. Since it may be supposed that some of the badly corroded pins were breaking and dropping off the fish during the 42-month period, the apparent percentage of severely corroded pins is a minimum estimate.

It is to be concluded from these results that, in tagging experiments involving the use of nickel pins, a minimum of 50% reach a seriously weakened condition by the end of 18 months and that the incidence of tag loss is probably very high.

TABLE I. Condition of nickel tagging pins by six month recapture intervals after release.

Months	No corrosion		Slight corrosion		Severe corrosion	
	Number	Per cent	Number	Per cent	Number	Per cent
0-6	14	74	3	16	2	10
7-12	36	40	21	24	32	36
13-18	21	16	46	34	66	50
19-24	27	14	76	39	93	47
25-30	15	12	35	27	77	61
31-36	11	8	27	20	97	72
37-42	4	15	3	11	20	74
42+	..	..	..	..	10	100

TESTS OF DIFFERENT METALS

METHOD

Tagging experiments employing a number of types of metal wire were conducted to obtain comparative data on the effects of corrosion. In January 1952, 2,000 lemon soles were tagged aboard M/V *Investigator No. 1* in a two-day period on a single fishing ground in the lower Strait of Georgia. In this experiment four types of pins or wire were used:

1. The standard nickel tagging pin (0.036-inch diameter).
2. Stainless steel wire (Type 316, dead soft, 0.032-inch diameter).
3. Silver wire (hard temper, 0.035-inch diameter).
4. Headless standard nickel pin (0.036-inch diameter).

It will be noted that two forms of nickel pin were used—one with the factory-formed head and the other with the head removed. On the latter a loop was twisted on the remaining wire in place of the head. This procedure permitted a better comparison with the stainless steel and silver wire which had looped heads rather than factory-formed heads.

In order to compare the recoveries of each type of pin it was necessary to ensure that the groups of fish used were not different in respect to length and sex. This was accomplished by using the four types in rotation during the course of the tagging operation. The 2,000 tags applied were distributed as follows:

Nickel-head	— 500 fish	Stainless steel	— 501 fish
Nickel-loop	— 500 fish	Silver	— 499 fish

Length distributions and sex ratios of the fish used with each type of pin were not substantially different. The average lengths of male fish were 305 mm., 304 mm., 304 mm. and 306 mm. for nickel-head, nickel-loop, silver and stainless steel, respectively. The average lengths of female fish were 378 mm., 376 mm., 382 mm. and 378 mm., respectively; while the percentage of females was 49.6, 51.2, 49.4 and 48.4, respectively. In view of these results it seemed reasonable to suppose that any difference in frequency of recapture would be associated with differences in suitability of the type of tag attachment.

RESULTS

Recaptures were made by commercial trawlers and began approximately one month after the date of release. It should be mentioned that the tagging was conducted on an aggregated spawning population. Subsequent to spawning, the stock disperses and does not undergo any substantial regrouping until the following year when the spawning process again occurs. Since the fishery is affected by these changes in concentration, the tag recoveries do not occur uniformly over the year. In the case in question small numbers of tags were recovered each month after tagging, but the bulk of the returns came one year later in the region of tagging (Table II). It will be noted that recoveries during the 12th month after tagging were greater than the sum of the recoveries in the first 11 months.

The lack of consistency (between pin types) in the recoveries during each

TABLE II. Number of tags recovered in each of the 25 months following release.

Pin type	Months after release												
	1	2	3	4	5	6	7	8	9	10	11	12	13
Nickel-head	1	6	6	2	1	..	5	4	4	7	3	48	6
Nickel-loop	2	1	6	3	1	3	7	..	8	7	3	77	3
Silver	3	4	6	..	5	8	2	4	3	7	4	57	1
Stainless steel	1	3	8	4	3	4	4	8	3	3	4	88	2

Pin type	Months after release													Total
	14	15	16	17	18	19	20	21	22	23	24	25		
Nickel-head	..	..	3	..	..	1	..	..	..	..	3	..	100
Nickel-loop	3	3	..	1	1	..	..	1	2	1	3	3	139
Silver	1	..	..	..	2	..	..	..	..	..	3	..	110
Stainless steel	4	2	2	..	2	1	1	1	2	2	6	..	158	

of the first 11 months and during the 13th to 25th months may be attributed to the experimental error involved in small numbers of recoveries. Hence the periods of low recovery are of little value either individually or as a single group. A ratio for grouped data would depend heavily on the pattern of recoveries over the months comprising the group.

In view of the annual nature of most trawl fisheries, the most practical information which can be derived from Table II lies in the recoveries at or about the end of the first and second full year after release. Accordingly the data in Table II have been condensed to place special emphasis on the recaptures during the 11th to 13th months and the 23rd to 25th months (Table III).

(a) RECOVERIES DURING THE 11TH-13TH-MONTH PERIOD. The theoretical expectation of the assortment of 296 recoveries in the 11th-13th-month period on a 1:1:1 ratio (Table III, column 1) is 74 in each category. This is to be compared with the actual assortment shown in Table III, column 4. If there are no differences in the resistance of the different pins to salt water corrosion or in the reactions of the fish to the various metals these should not differ significantly. Actually the χ^2 value of 12.65 is highly significant ($P < 0.01$).

In order to reduce the chance that this deviation from the expected 1:1:1:1 ratio arose from the distribution of recaptures in months 1-10, the numbers caught during months 1-10 have been subtracted from the numbers released to obtain the numbers still unrecovered at the beginning of the 11th month (Table III, column 3). However, the expected ratio here differs so slightly from the original that the χ^2 value is little altered (12.41).

(b) RECOVERIES DURING THE 23RD-25TH-MONTH PERIOD. During this period 21 recoveries were made. The expected distribution, as computed from the number of tagged fish unrecovered at the beginning of the 23rd month (Table III, column 6), was 5.57, 5.09, 5.46 and 4.88. This may be compared with the actual distribution shown in column 7 of Table III.

The difference between these two distributions is very noticeable, and is of the same pattern as that which was evident during the 11th-13th-month period. However, as might be expected in view of the small number of recoveries, the value of χ^2 is small (4.75) and not significant ($P = 0.10-0.20$).

TABLE III. Number of tags recovered at the end of the first year (11th-13th mo.) and at the end of the second year (23rd-25th mo.).

	1	2	3	4	5	6	7
Pin type	Number tagged	Recaptures 1-10 mos., incl.	No. un-recovered beginning of 11th month	Recaptures 11-13 mos., incl.	Recaptures 14-22 mos., incl.	No. un-recovered beginning of 23rd month	Recaptures 23-25 mos., incl.
Nickel-head	500	36	464	57	4	403	3
Nickel-loop	500	38	462	83	11	368	7
Silver	499	42	457	62	3	393	3
Stainless steel	501	41	460	94	15	351	8
Totals	2,000	157	1,853	296	33	1,515	21

DISCUSSION

(a) DIFFERENCES IN NUMBER OF RECOVERIES. As might have been expected from results shown earlier on the high incidence of corrosion in nickel tagging pins, the standard nickel pin gave low returns during the 11th-13th months as compared with the other types (Table III, column 4). During this period the number of nickel-head tags recovered was only 60% of the number in the best represented type (stainless steel). The difference was shown to be statistically significant ($P < 0.01$). During the 23rd-25th months (Table III, column 7) the nickel-head pins were only 37.5% of the number of stainless steel.

Microscopic examination of the tags recovered during the period of the experiment provided the explanation of this difference. While nickel pins showed a high incidence of corrosion similar to that illustrated in Figure 2, no case of even slight corrosion (or wear) was encountered in the 158 stainless steel tags recovered. From all appearance stainless steel (Type 316)² seems to possess maximum durability in sea water.

Regarding tags attached with silver wire, the numbers recovered in the 11th-13th-month period were 65% of the number of stainless steel recaptures. This difference was found to be statistically significant ($P < 0.01$). In the 23rd-25th-month period the number of silver recaptures was 37.5% of the number of stainless steel recaptures.

Silver pins apparently remained in good condition until the 11th and 12th months of the experiment, at which time they began to show signs of thinning. The thinning occurred at those sections of the pin which were in contact with the tagging disc, and presumably was the result of abrasion brought about by body movements of the fish. Silver is considerably softer than the other metals and hence is more susceptible to this type of wear. Although slight corrosion was noticed in one or two recoveries, the main deficiency in this metal seemed to be its tendency to weaken by thinning. This confirms observations by Calhoun *et al.* (1951).

²According to metallurgical reports, Type 316 is superior to all other types of stainless steel in respect to resistance to corrosion in salt water. It differs from Type 302, which is now being used by some other agencies for tagging, mainly in its content of molybdenum and controlled carbon content.

There was no statistically significant difference between recoveries of nickel-loop pins and stainless steel, either in the 11th-13th-month interval or in the later interval.

The remarkable difference between the recoveries of nickel-head and nickel-loop throws light on the source of weakness in the conventional nickel pin. Stresses set up in the formation of the head in the manufacturing process apparently weaken the pin at that point and make it vulnerable to corrosion. Microscopic examinations of the nickel pin have shown that most cases of corrosion commence at or near the head.

(b) DIFFERENCES IN THE CONDITION OF TAG WOUNDS. At this point it is important to consider other attributes of the four types of tags. A classification of the condition of tagging wounds associated with each type is shown in Table IV. A tagging wound was considered to be in "good" condition when there was no sign of abrasion or erosion of the flesh under the tagging discs. "Fair" condition denotes cases where slight inflammation or abrasion was apparent on one or both sides of the fish. When tagging wounds were large, raw or deeply eroded they were classed as "poor".

It will be noted that the percentage of fish in "good" condition was highest in the case of stainless steel, and lowest in the case of nickel-head. The highest percentage of "poor" wounds occurred with the two types of nickel.

While recoveries of nickel-loop tags have been shown to approach those of stainless steel (Table III), it is apparent that nickel-loop is much less suitable in respect to its effect on the fish.

The reason for these differences in condition of wounds is not clearly understood. They may be the result of differences in the reaction of body tissues to the type of metal, or of differences in physical properties of the metal affecting the ease of tag attachment.

(c) THE QUESTION OF A CORRECTION FACTOR. If the assumption is made that stainless steel is perfect or near-perfect in durability on the fish, in view of its capacity to resist corrosion and cause a minimum of irritation, then some form of correction can be computed for losses in other types of metal.

In Figure 3, the ratio of nickel-head to stainless steel has been plotted for four-month (running) intervals. This smoothing procedure has been necessary to minimize the fluctuations, resulting from the experimental error arising from small numbers of recoveries.

The trend line for these data, although shown as a straight line,³ is probably slightly concave upwards. On a straight-line trend the ratio of nickel to stainless steel would theoretically become zero at the 31st-34th-month period, that is, nickel tags would no longer be available at that time. Data from earlier experiments with nickel show that recoveries do occur after that much time, but are usually quite rare after the 36th month. As shown in Table I only 5% of the recoveries from experiments with nickel occurred after the 36th month.

In view of the greater reliability of the estimated ratios at the intervals 1-4, 11-14 and 22-25, it is reasonable to regard the trend for practical purposes as

³The equation for this line is $Y = 0.9102 - 0.0296 X$.

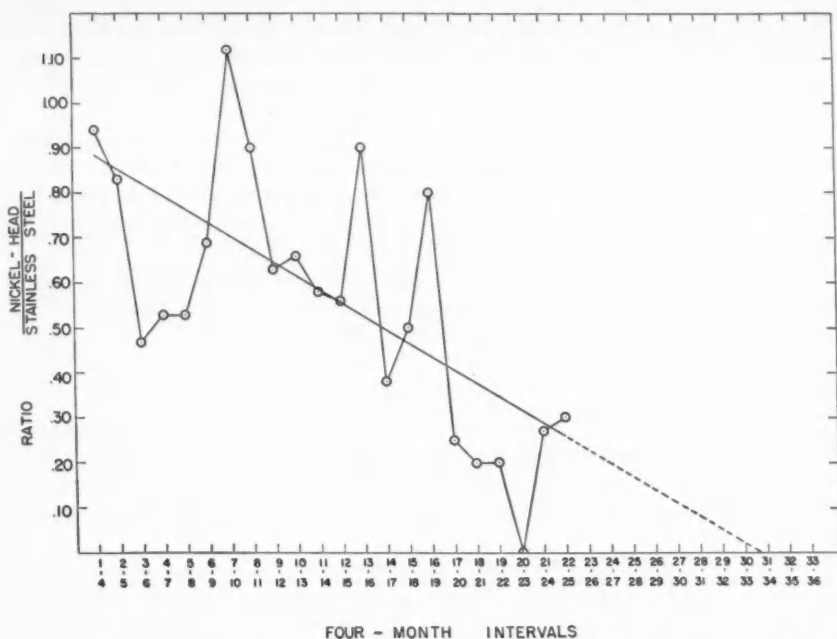


FIGURE 3. The ratio of recoveries of nickel-head to stainless steel in four-month (running) intervals.

being straight during the first 25 months. From this trend line estimates can be made of the probable correction required on the recoveries of nickel pins. For example, let it be supposed that, 11 to 14 months after a tagging experiment (with nickel alone), a fishery took place in which, say, 100 tags were recovered. Since the ratio of nickel to stainless steel for this interval is approximately 0.60, the number which should have been recovered is estimated as $100/0.60 = 167$.

If 100 tags were recovered during the 21st-24th-month period, then the estimate of the number which should have been recovered is $100/0.30 = 333$.

In computing mortality rates on the basis of corrected recoveries it would have to be kept in mind that the assumption of perfect durability in the "control" tag—namely, stainless steel—is not entirely sound. It would be folly to accept such an assumption regarding any button-type tag. As shown in Table

TABLE IV. Condition of tagging wound at time of recapture.

Pin type	Good	Fair	Poor	Number examined
	%	%	%	
Nickel-head	34.2	25.6	40.2	82
Nickel-loop	46.7	23.0	30.3	122
Silver	49.0	25.0	26.0	96
Stainless steel	60.3	21.3	18.4	141

IV, tag wounds are substantial even in cases where stainless steel has been used. It must be presumed, therefore, that a certain number of losses occur, perhaps as a result of the tag being torn from the fish or wearing its way through the body.

Another source of error which is equally difficult to assess is the possibility that the batches of nickel tagging pins purchased from time to time over the past decade have differed radically in their capacities to resist salt water corrosion. Thus, a factor computed from tests with one particular batch might over-correct for some experiments and under-correct for others.

Regardless of these limitations, it seems that a judicious attempt to correct recoveries for losses through corrosion will serve to reduce greatly the discrepancy between apparent and actual mortality rates.

SUMMARY

1. It is apparent from the high rate of corrosion in nickel tagging pins that they are worthless for long-term quantitative studies of marine fish populations. In flâtfish tagging experiments off the British Columbia coast, severe corrosion and weakness was found in more than 40% of the tag recoveries by the end of the first year.

2. In a comparative experiment in which nickel, silver and stainless steel pins were tested, recaptures at the end of the first year were highest of tags attached with stainless steel. The ratio of recaptures of manufactured nickel pins to stainless steel at the end of the first year was 0.61:1.00 and at the end of the second year 0.38:1.00.

3. Silver wire showed little corrosion, but considerable thinning where contact was made with the tagging discs. Losses from the effects of wearing were indicated at the end of the first year in a silver:stainless steel ratio of 0.66:1.00. At the end of the second year the ratio to stainless steel was the same as that for nickel (0.38:1.00).

4. That the source of weakness (vulnerability to corrosion) in the manufactured nickel pin lies at or near the head was demonstrated in tests where the head was removed and replaced by a loop. Recoveries of the nickel-loop pin at the end of the first and second years were not significantly different from those of stainless steel.

5. Tagging wounds at the time of recapture were classified according to the type of wire used. Wounds were least severe where stainless steel had been used and most severe where nickel had been used.

6. On the basis of the ratio between the recaptures of nickel and stainless steel pins at various intervals after tagging, correction factors have been computed to account for losses of nickel pins through corrosion.

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More Folliculinids (Ciliata Heterotricha) from British Columbia¹

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IN British Columbia, the first record of a ciliate of the family Folliculinidae was made by Wailes (1928), in his extensive study of freshwater and marine Protozoa. In this publication is figured a single empty test of what was considered to be *Folliculina boltoni* Kent, from a large freshwater lake. In a later publication Wailes (1943) makes no mention of this species, but describes a salt-water species, *Folliculina ampulla* O. F. Müller, now known as *Lagotia viridis* Wright, taken along shore on algae, etc., and dredged down to 40 meters in the Strait of Georgia.

On a shore ascidian taken near Nanaimo were found some 400 tests of the following folliculinids: *Lagotia viridis* Wright, *Parafolliculina amphora* Dons, *Parafolliculina violacea* Giard, as identified by Andrews (1948).

Recently the known folliculinid fauna of British Columbia has been increased by specimens taken in Pendrell Sound, where in midsummer the salinity may fall to 16 parts per thousand, and from Refuge Cove, where the salinity ranges from about 22 parts per thousand in September, to 28 parts per thousand in winter and early spring.

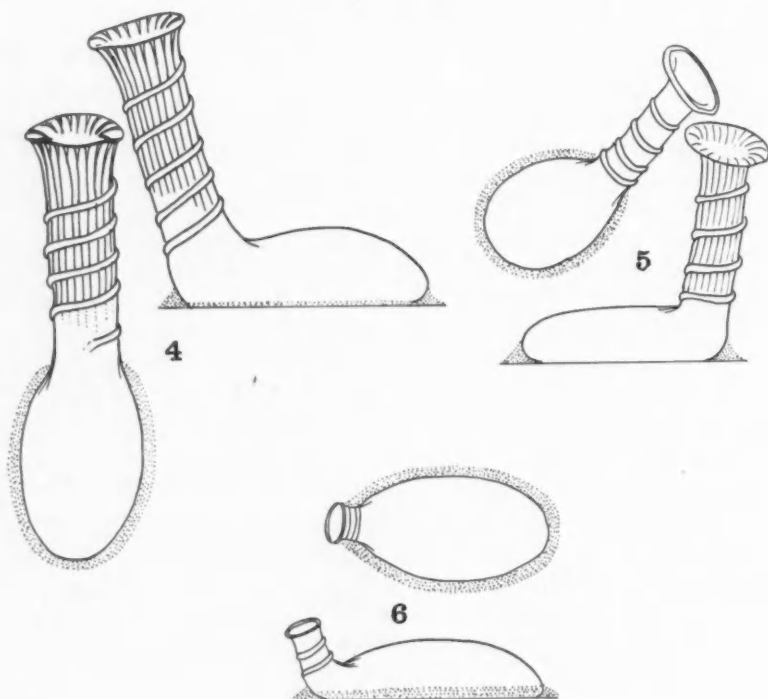
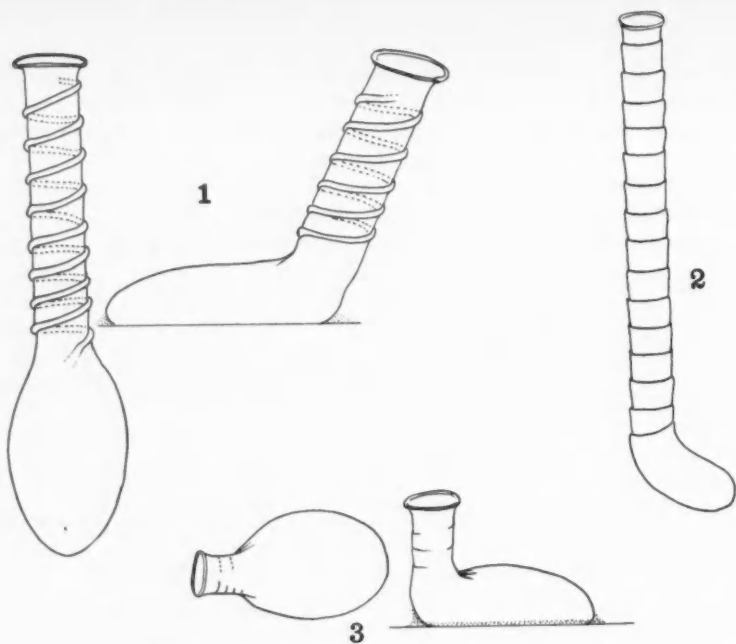
In these localities several species of folliculinids were found on oyster shells suspended a few feet below the surface. Some identifications were confirmed by Dr. Jovan Hadzi at the University of Ljubljana, Yugoslavia, to whom part of the material was sent, and upon more intensive study he was able to increase the number of forms found to nine.

The most abundant were *Lagotia expansa* Levinsen, including some large individuals known as *Lagotia gigantea* Dons; next in abundance was *Metafolliculina andrewsi* Hadzi; then *Lagotia donsi* Hadzi; rather abundant were *Claustrofolliculina clausa* Hadzi; then a colourless *Folliculina* which may be an undescribed species not identifiable from the material available; some *Parafolliculina americana* Hadzi, which at first were taken to be *P. amphora* Donsi, a few *Planifolliculina cumbens* Hadzi and a single test of some unknown folliculinid not identifiable.

Adding the above to the previous records, we have the following list of folliculinids recorded from British Columbia:

1. *Metafolliculina andrewsi* Hadzi. 2. *Metafolliculina producta* Wright. 3. *Lagotia viridis* Dons. 4. *Lagotia expansa* Levinsen. 5. *Lagotia gigantea* Dons. 6. *Lagotia donsi* Hadzi. 7. *Folliculina boltoni* Kent. 8. *Claustrofolliculina clausa* Hadzi. 9. *Parafolliculina amphora* Dons. 10. *Parafolliculina americana* Hadzi. 11. *Parafolliculina violacea* Giard. 12. *Planifolliculina cumbens* Hadzi.

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In the above list, the record of the freshwater species *Folliculina boltoni* Kent is very weak; the occurrence of *Metafolliculina producta* Wright needs confirmation; *Lagotia gigantea* Dons seems but a variety of *Lagotia expansa* Levinsen; specimens formerly called *Lagotia viridis* Dons may have been *Lagotia expansa* Levinsen; and, specimens called *Parafolliculina amphora* Dons may have been *Parafolliculina americana* Hadzi; but though thus reduced, the list may yet be increased by rediscovery of the unidentified *Folliculina* and another form seen by Hadzi.

As is often the case with Protozoa, folliculinids have a wide distribution; for instance, *Lagotia expansa* Levinsen was first found off Denmark and later, Greenland and Spitzbergen and in the Mediterranean and Adriatic; and was recently discovered by Ringuet (1953) along the coasts of Tierra del Fuego.

That any folliculinids are known in a country so recently civilized contrasts with the absence of any records from Japan and China with their ancient civilizations and extensive shores. This contrast may be correlated with the relative importance of the microscope in different civilizations.

The folliculinid material was provided by Mr. and Mrs. C. Berkeley, Nanaimo, and D. B. Quayle, Provincial Shellfish Laboratory, Ladysmith, B.C.

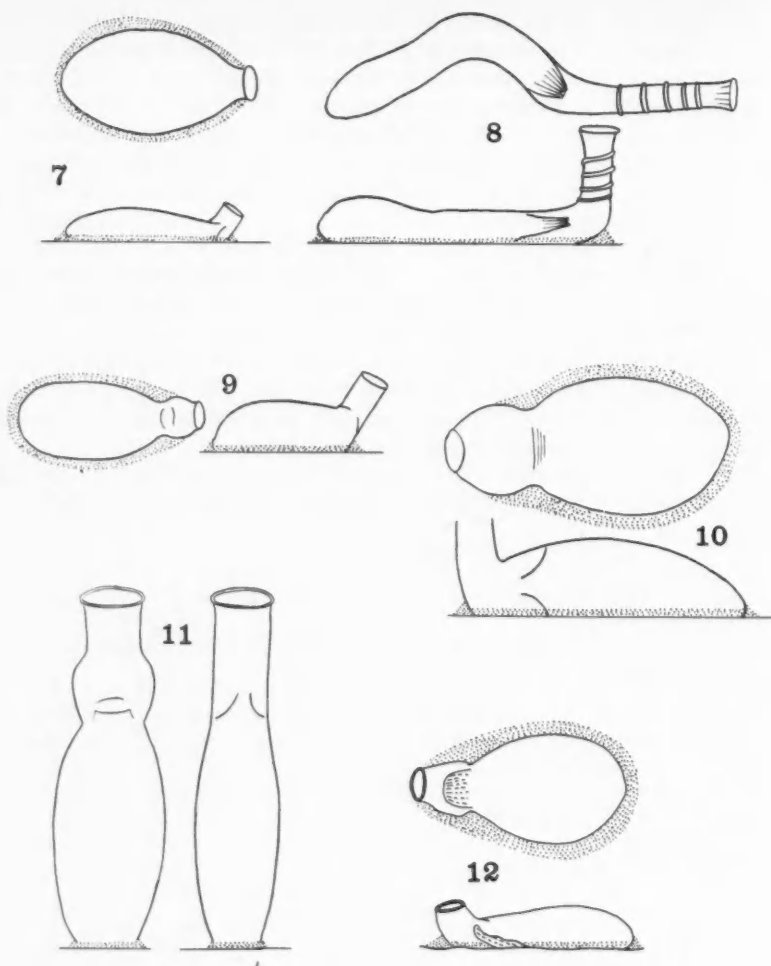
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FIGURES 1-6

Outlines of empty tests of folliculinids recorded from British Columbia. Each shows a top view and then a side view of the same or similar test.

1. *Metafolliculina andrewsi* Hadzi. Overall length 630 μ ; height of neck 360 μ ; length of body 280 μ ; width of body 130 μ ; depth of body 85 μ . 2. *Metafolliculina producta* Wright. Length of neck 550 μ ; length of body 148 μ . 3. *Lagotia viridis* Dons. Overall length 462 μ ; height of neck 200 μ ; length of body 262 μ ; width of body 150 μ ; depth of body 26 μ . 4. *Lagotia expansa* Levinsen. Overall length 460 μ ; height of neck 220 μ ; diameter of collar 125 μ ; diameter of neck near body 66 μ ; length of body 237 μ ; width of body 165 μ ; depth of body 102 μ . 5. *Lagotia gigantea* Dons. Height of neck 600 μ ; length of body 400 μ ; width of body 300 μ ; depth of body 105 μ . 6. *Lagotia donsi* Hadzi. Overall length 270 μ ; width of body 84 μ ; depth of body 37 μ . (After a sketch by Dr. J. Hadzi.)



FIGURES 7-12

Outlines of empty tests of folliculinids recorded from British Columbia. Each shows a top view and then a side view of the same or similar test.

7. *Folliculina boltoni* Kent. Overall length 200 μ . 8. *Claustrofolliculina clausa* Hadzi. Height of neck 194 μ ; length of body 430 μ ; width of body 54 μ . (After a sketch by Dr. J. Hadzi.) 9. *Parafolliculina amphora* Dons. Overall length 225 μ ; height of neck 75 μ ; length of body 150 μ ; width of body 92 μ ; depth of body 50 μ . 10. *Parafolliculina americana* Hadzi. Overall length 175 μ ; width of body 97 μ ; depth of body 35 μ . 11. *Parafolliculina violacea* Giard. Overall length 291 μ ; height of body 210 μ ; height of neck 75 μ ; width of body 105 μ ; depth of body 55 μ . (After a sketch by Dr. J. Hadzi.) 12. *Planifolliculina cumbens* Hadzi. Overall length 142 μ ; width of body 70 μ ; depth of body 15 μ . (After a sketch by Dr. J. Hadzi.)

The Smallmouth Bass Fishery of South Bay, Lake Huron^{1,2}

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ABSTRACT

The smallmouth bass (*Micropterus dolomieu*) population of South Bay, Lake Huron and the sport fishery imposed on it have been studied by means of marking and creel census carried out during the years 1947 to 1952 inclusive. Population estimates of legal-sized bass (over 10 inches—fork length), based on the recovery of marked fish, show a decrease from 5,900 fish in 1947 to 2,900 in 1949 with an increase again to 5,700 in 1952. The number of bass caught per 100 rod-hours in these years was 89, 51 and 87, respectively. The recovery of the population from its low in 1949 was due solely to the 1947 year-class which dominated the fishery in 1950, 1951 and 1952, contributing 34%, 71% and 67%, respectively, of the anglers' catch in these years. Analysis of scale samples of the anglers' catch shows considerable variation in year-class strength. In contrast to the 3,500 fish contributed to the anglers' creel by the 1947 year-class, the 1945 year-class contributed only 400 fish.

South Bay bass enter the sport fishery in small numbers at age III and 70% of the anglers' catch consisted of age-III to age-V fish. Sixty per cent of the legal-sized population of bass present in South Bay in one year are taken by anglers in the succeeding 4-5 years at the present exploitation.

A large percentage of the bass population is located in the Inner Basin of South Bay where they are dispersed in varying concentrations along the shoreline. During the five-year study 3,331 bass were tagged and, although the loss of tags was high, 692 were recaptured by trap nets in the same season they were released. Eighty-five per cent of these were taken within two miles of their release point. Of 60 bass recaptured a year after tagging, 43 (72%) were taken within two miles of their release point. Only five per cent of all recorded recaptures were caught over five miles from their release point. Larger bass tended to range farther than small bass.

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INTRODUCTION

IN 1947 the Department of Lands and Forests of Ontario, with the assistance of the Ontario Federation of Commercial fishermen, undertook an extensive investigation termed "The South Bay Experiment". The aim of this investigation was "to assess the value of exerting equal fishing pressure as far as possible on all species of fish present in a body of water as opposed to the general practice of selectively fishing one or two sport or commercial species".

The body of water selected for this experiment was South Bay, located on Manitoulin Island at Latitude 45° 37' and Longitude 81° 54'. South Bay (Fig. 1) is 16 miles long by approximately 2 miles wide (26 by 3 kilometres), and opens into Lake Huron by a narrow gut 200 yards (180 metres) in width. South Bay covers 20,000 acres (8,000 hectares) and is composed of two basins termed here the Inner Basin and the Outer Basin. The greatest depth of water (32 fathoms—59 metres) is to be found in the Inner Basin, whereas the Outer Basin is relatively shallow and uniform at 6 to 7 fathoms (11–13 metres).

Fifty species of fish have been identified from South Bay to date. This number will be higher when the minnows are fully investigated. The game species present are lake trout (*Cristivomer namaycush*), smallmouth bass, northern pike (*Esox lucius*), rock bass (*Ambloplites rupestris*) and yellow perch (*Perca flavescens*). One largemouth bass (*Micropterus salmoides*) has been taken in South Bay and the catch of yellow pike-perch (*Stizostedion v. vitreum*) approximates 10 per year. The more abundant non-game species are smelt (*Osmerus mordax*), cisco (*Leucichthys* sp.), common white sucker (*Catostomus commersoni*) and whitefish (*Coregonus clupeaformis*). In accordance with the aim of the experiment all species other than game fish have been heavily fished with commercial gear in the years 1947–1952. The game species have been subjected to the usual angling pressure, and a creel census has been conducted to assess this pressure and the characteristics of the angling catch.

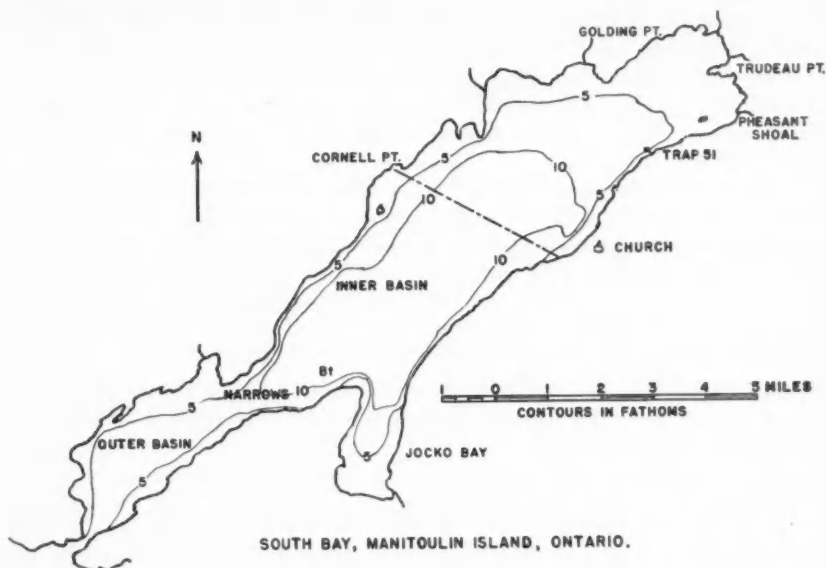


FIGURE 1. Map of South Bay.

To determine the effect of the heavy removal of non-game species on the sport fishery, a program of netting and tagging of game fish has been carried out as well as a creel census. This paper is an analysis of the smallmouth bass (*Micropterus dolomieu*) fishery of South Bay for the years 1947-1952 inclusive. The heavy removal of non-game species is not expected to affect the smallmouth bass fishery in such a short period but this analysis should provide a basis for comparison of the fishery in future years.

ACKNOWLEDGMENTS

Many persons have contributed much toward the study which has resulted in the preparation of this paper. I am highly indebted to Dr. F. E. J. Fry for the opportunity to undertake this investigation and for his continued direction and advice. I wish to thank the Research Division of the Ontario Department of Lands and Forests for sponsoring this work and for permission to publish these data, and Dr. W. J. K. Harkness, Chief of Fish and Wildlife Division, for making available time for their analysis. I am grateful to all the personnel of the South Bay Laboratory, especially to J. Budd, K. Irizawa and B. Wilson, for their assistance and advice. The kind cooperation of lodge owners, guides and anglers of South Bay is deeply appreciated.

METHODS

NETTING

Smallmouth bass have been netted and tagged in South Bay in the years 1947-1952 inclusive. In these six years from 5 to 10 trap nets have been used

primarily for the capture of bass. In the years 1947-1950 bass netting began in the first week of July and extended to the end of August. In 1951 a small number of bass were incidentally tagged in other netting operations in May and June. In 1952 bass tagging was carried out in the last three weeks of June. Seven pound nets employed in other fishing operations in these years also caught a small number of bass.

The trap nets used were chiefly of two sizes. Those used in 1947-1949 were small, the pots being 12 feet long, 6 feet wide and 6 feet deep, with a 2½-inch mesh, stretched measure. The lead of these nets was 200 feet long and 6 feet deep with a 5-inch mesh. In 1947 and 1948 these nets were set either singly or in strings of three from the shore. In 1950 four larger traps were used for fishing deeper water. The pots of these traps were approximately 18 feet long, 9 feet wide and 9 feet deep with a 3-inch mesh. The leads of these nets were 400 feet long and 9 feet deep with a 5-inch mesh. All trap nets were set in depths of from one to five fathoms depending on the length of their lead and the slope of the bottom.

TAGGING

After the bass were removed from the net, which was fished from a punt, they were placed in a washtub and taken to the power boat to be tagged. The tagging operation required one minute on the average and was as follows: The tag was attached to the fish, a specified fin clipped, the fish measured to the nearest half inch, a scale sample taken, previous marks noted and the fish released at point of capture. Usually this work was done by one man, with another recording the data.

The tag used in 1947 has been described by Fry (1947). The one used in the years 1948-1952 was an oval celluloid disc 0.5 by 0.3 inches with a serial number and "Dept. of Lands and Forests (Ont)" printed on it.

A 9-inch piece of nylon monofilament leader (6-pound test) was inserted through a hole in the tag and tied with a clinch knot (Lagler, 1952). The nylon leader was threaded to a needle which was forced through the flesh of the fish, carrying the leader with it. The leader was then removed from the needle, brought around as tight as possible, returned through the hole and secured to the tag by two half-hitches. The surplus leader was trimmed off with a pair of scissors. The point of attachment of the tag has varied considerably from year to year as is illustrated in Figure 2.

Tagging data covering the 6-year period are presented in Table I. A total of 3,647 smallmouth bass were marked in South Bay in these years either by tagging or clipping or by a combination of both methods. The tagging methods used have not been very satisfactory. In the years 1947, 1948, and 1949 and 1952, when bass were both tagged and clipped, the ratio of tagged and clipped fish to clipped fish (with tags lost) among the recaptures in the season following indicated an 80% loss of tags. The small number of recaptures of bass tagged but not clipped in 1950 and 1951 indicates a similar high loss of tags in these years also.

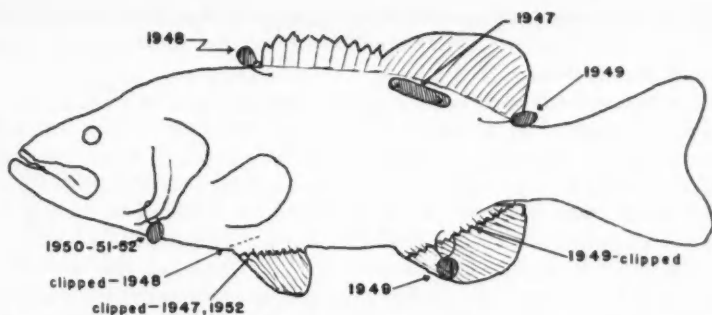


FIGURE 2. Various markings on South Bay smallmouth bass in the years 1947-1952.

Insufficient anchorage and the gradual cutting of the nylon leader through the flesh or bone appears to be the main reason for the high loss of tags. Larger fish provide more anchorage for the tag and retain their tags longer than smaller fish. Recapture records in the year after tagging show that 90% of the fish under 13 inches lose their tags over the winter compared to a 60% loss for fish over 13 inches in length.

AGE AND GROWTH

AGE COMPOSITION

Age determinations were made from scale impressions on cellulose acetate slides. Five or six scales from each fish were impressed on a slide and the impression magnified by a scale projector. Ages are given as the number of completed annuli in the scale. Thus, a fish whose scale contains three annuli and

TABLE I. Records of smallmouth bass tagging and marking in South Bay in the years 1947-1952. (The year of tagging is designated as year n .)

Year	Tag attachment	Fin clipped	No. tagged and clipped	No. clipped only	% tags lost in year n	% tags lost by year $n+1$
1947	dorsal fin (posterior)	left pelvic	153	200	61	100
1948	dorsal fin (anterior)	right pelvic	438	105	19	77
1949	dorsal fin (posterior)	anal	1,172	11	6	71
1950	preopercular bone	none	987	...	?	?
1951	preopercular bone	none	152	...	?	?
1952	preopercular bone	left pelvic	429	...	76	?

some marginal growth is designated as age-group III. Age determination of bass over eight years of age was extremely difficult and the values presented are at best an approximation.

The age composition of bass caught by anglers and by nets in the years 1948-1952 is presented in Table II. The netting took more of the younger fish than were taken by angling. The 10-inch legal limit imposed on anglers prevents the taking of bass of age-groups I and II and a high percentage of age-group III. The length distribution of 151 bass of age-group III taken by nets shows 78% to be under the 10-inch legal limit. Taking the foregoing into consideration, the age composition of bass over 10 inches in length is much the same for both netting and creel census data. Both nets and anglers took bass up to and including Age XII but the greater percentage of the catch was made up of age-groups III to VII inclusive.

There was a notable change in the age composition of the catch from 1948 to 1952. In 1948 92% of the net catch was age-IV and older. This group dropped to 55% in 1949 and to 46% in 1950. In 1951 this group increased to approximately the 1948 level (92%) and in 1952 the entire catch was age-IV and older. The main reason for this trend was the scarcity, or weakness of several year-classes followed by the entrance of the outstanding 1947 year-class. This year-class made up 19% of the net fishery in 1949, and 51% in 1950. Although it could only enter the sport fishery to a limited degree at age III its contribution (34% of the anglers' catch) was greater than that of any other year-class in 1950. There are not sufficient data to determine the age composition of the trap net catches in 1951 but the creel census shows the important contribution (72%) of the 1947 year-class at age IV to the angling fishery in that year. In 1952 the 1947 year-

TABLE II. The percentage age composition of smallmouth bass caught by nets and by angling in South Bay in the years 1948-1952.

Age	Year of capture									
	1948		1949		1950		1951	1952		
	Nets	Ang.	Nets	Ang.	Nets	Ang.	Ang.	Nets	Ang.	
II	3		19		3					
III	5	2	26	20	51	34	4		0.3	
IV	20	14	7	8	20	26	72	20	26	
V	25	32	19	18	6	11	12	68	67	
VI	25	29	10	26	8	14	4	7.5	3.3	
VII	16	17	11	16	6	10	4	1	0.5	
VIII	3	4	6	10	3	4	2	2	1	
IX	3	1	1	0.8	2	0.8	1	1	1	
X		1	0.6	0.8	1		1	0.5	0.5	
XI			0.2			0.2			0.2	
XII			0.2	0.4					0.2	
Number examined	114	381	440	256	266	303	343	422	615	

class continued to carry the angling fishery by contributing 67% of the year's catch.

The negligible representation of age-groups II and III in the 1951 and 1952 net catches possibly indicates a lack of strength in the 1949 and 1950 year-classes.

RATE OF GROWTH

The growth rate of South Bay bass is very similar to that found by Doan (1940) for Lake Huron bass. South Bay bass are slower growing than the bass of Lake Nipissing (Tester, 1932) and Lake Opeongo (Doan, 1936) but considerably faster than Georgian Bay bass (Doan, 1940).

In Table III are presented the number of fish for which age determinations were made and the length and weight attained by these fish at various ages. Creel census values have been added to the values for netted fish for additional strength in the growth curve. The average weight for each age-group is based only on creel census data, as bass captured and released from nets were not weighed. The bracketed values are not representative owing to selection of nets at this age and also the 10-inch limit imposed on anglers. The average length of 9.2 inches should be close to the true value for age-group III and has been plotted.

The growth rates of South Bay bass and Lake Opeongo bass as calculated from age determinations are presented in Figure 3. The shape of these two curves is almost identical, although Lake Opeongo bass are faster growing. As a good deal of uncertainty existed in aging the older fish, reference was made to the tagging data to check the length increments of fish recaptured a year after tagging. These length increments have been averaged for bass of various length-groups and are presented in Table IV.

Using a method suggested by Fry (1951), the length increments were fitted

TABLE III. Rate of growth of smallmouth bass in South Bay in the years 1947-1952 inclusive. (The bracketed values represent the catch but not the population.)

Age	Number of fish			Av. fork length	Av. weight (creel census only)
	Creel census	Netting	Total		
				<i>inches</i>	<i>ounces</i>
II	1	98	99	(8.1)	
III	177	305	482	(9.2)	(8.7)
IV	439	123	562	10.4	11.6
V	328	151	479	11.6	16.6
VI	321	115	436	12.8	22.0
VII	176	120	296	13.9	22.8
VIII	74	64	138	14.6	33.6
IX	18	28	46	15.7	41.0
X	8	10	18	15.9	41.0
XI	2	5	7	17.0	56.0
XII	2	1	3	17.7	70.0

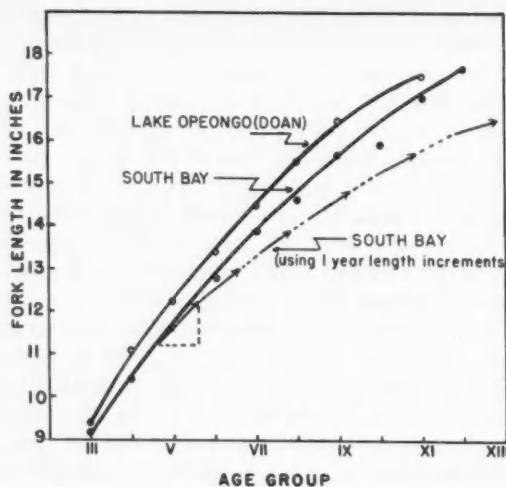


FIGURE 3. Growth rates of smallmouth bass from South Bay and Lake Opeongo.

to the growth curve determined by scale readings. The length increments were anchored to the growth curve at 11.25 inches, as age determination of bass in this size-range is considered accurate. The average increase in length of bass in length-group 11.25 inches was one inch in one year and this point is plotted on the graph. The slope of the line joining this point to the anchor point illustrates the rate of growth. By plotting the increments for all length-groups a growth curve is formed. The dotted lines in the curve are the result of the older fish not increasing in length sufficiently in one year to bring them into the next length-group.

As can be seen in Figure 3 the growth curve based on length increments shows a slower growth rate, especially in the larger fish. Since both South Bay growth curves are based on approximately the same number of fish for the larger sizes, and in most instances on the same fish, it appears that the outer annuli of

TABLE IV. Average length increments of smallmouth bass tagged in year n and recaptured in year $n + 1$.

Length-group	Number of fish	Average length increment
<i>inches</i>		<i>inches</i>
9.2	3	1.4
10.2	2	1.1
11.2	12	1.0
12.2	23	0.8
13.2	20	0.7
14.2	27	0.6
15.2	13	0.5
16.2	7	0.3

these fish are not being detected by the method used; possibly the margin does not register completely on the impressions of larger scales. If more bass manage to retain their tags into the following year, the use of length increments is probably the answer to a more accurate growth curve for older fish. There is also the possibility that the slower growth rate resulted from the attached tag, although the attachment was such that it did not interfere directly with the feeding of the bass.

MATURITY

No observations of spawning bass have been made in South Bay and the age composition of spawning fish is not known. In Table V are listed the percentages of both male and female bass of age-groups III, IV and V that were

TABLE V. The percentages of mature smallmouth bass in age-groups III, IV and V in South Bay.

Age	Mature male	Mature female	Fish examined
III	50	0	147
IV	78	42	378
V	92	75	451

noted to be mature in the examination of the anglers' catch. It was difficult to determine the state of maturity of many of the female bass in these age-groups and the percentages listed are subject to error. Out of 1,495 bass examined over the six-year period, 49.2% were males. Fifty per cent of the male bass examined were mature at age III, 78% at age IV and all had reached maturity by their sixth year. Approximately half of the females attain maturity at age IV, about 75% by age V and all are mature at age VI. Although half of the females appear mature at age IV, it is believed that very few of these spawn in that year.

BASS MIGRATIONS

In 1947 and 1948 nets were set at any suitable location along the shoreline of South Bay. In these two years 92% of the bass taken in nets were captured in the northeast half of the Inner Basin (Fig. 1) and consequently trap netting was more or less confined to this area in the following years. The Narrows and Outer Basin areas have been fished extensively with pound nets in all years but the bass catch in these has been negligible. The fact that only 11% of the anglers' catch in the six-year period has come from areas other than the northeast half of the Inner Basin justifies the concentrating of trap nets in that area.

In Table VI the relative population densities at various locations in July and August of the years 1947-1950 are expressed as the average catch per lift of trap net set in these areas⁴. There are no comparable figures for 1951 and 1952 since netting in these years took place in May and June.

⁴Only original captures are shown in Table VI because a few bass got the "net habit" and were recaptured four or five times in a short period of time. This procedure discriminates against the years of greater fishing, making their catch per lift somewhat too low, relatively, when used as an index of population abundance; however, since the number of recaptured fish was small in any year, this effect is not of any consequence.

TABLE VI. Catch per trap-net lift of smallmouth bass at various locations in South Bay in the years 1947-1950 (original captures only).

Location	Year of capture			
	1947	1948	1949	1950
Trudeau Point	...	6.8	7.6	24.3
Pheasant's Shoal	6.0	5.0	7.0	16.8
North of Church	...	...	9.4	9.5
South of Church	8.5	3.4	10.9	6.6
Cornell Point	...	4.6	8.2	25.8
Golding Point	...	5.2	7.9	20.7
Jocko Bay (area)	0	0.8	...	1.5
Narrows (area)	1.0	2.3	...	...
Lower Basin (area)	1.0	...	...	...
Total lifts	177	189	121	84

Table VI, as well as showing a low population density in all areas except the Inner Basin, also indicates a two-fold increase in population from 1949 to 1950. A study of the age composition of the net catches shows how this rapid increase took place.

RECAPTURES IN NETS

As the netting data provide more accurate information than angling returns concerning migration, they will be considered first. Although these data are limited by the short netting season and the small number of trap nets used, a good deal has been learned of bass movements.

The data indicate that the greater percentage of South Bay bass do not range any distance in the months of July and August and that large bass tend to range farther than small bass. Only 4% of recaptured bass under 10 inches in length were taken over $\frac{1}{2}$ mile from their release point compared to 14% for 10 to 13-inch bass and 41% for bass over 13 inches in length (Table VII).

Records of 681 tagged fish recaptured in the same season from 1947 to 1951 show only 12 bass moving into the northeast section of the Inner Basin from elsewhere and five bass moving from it to the Jocko Bay and Lower Basin areas. Of all recorded recaptures in nets, 78% were taken in the net from which they were

TABLE VII. Distances travelled by tagged bass of various length-groups from point of release to point of recapture in year *n*.

Length-group (inches)	Distance (miles)				Total recaptures
	0-0.5	0.5-2.0	2.0-5.0	over 5	
7.0-9.9	116	0	4	1	121
10.0-12.9	220	17	15	5	257
over 13.0	121	33	32	20	206
All length-groups	457 (78%)	50 (8.5%)	51 (8.5%)	26 (5%)	584

originally tagged or in nets within one-half mile of it. Very few (5%) tagged bass were recaptured over five miles from their point of release. Snyder (1932) released 150 tagged bass in the eastern end of Lake Ontario, and of the 19 reported recaptures none were taken over three miles from their release point. Cuerrier (1943) reports that bass tagged in the Chateauguay River, Quebec, at spawning time were recaptured by anglers during the summer in Lac Saint-Louis. The greater percentage of the recaptures were made within 8 miles of the release point, although one bass was recaptured 30 miles away. Stone *et al.* (1951), in studies of smallmouth bass in the Lake Ontario-St. Lawrence River region, have noted the existence of a number of local populations of bass with little intermingling between them. It would appear that a similar situation exists in South Bay. However, it should be remembered that the South Bay data (Table VII) are valid only for the tagging period of July and August and that the average time between release and recapture is about one month.

Very few bass carried tags into the next year and these were mainly the larger fish. The minimum distances these fish travelled are presented in Table VIII. It is realized that these fish may have undergone extensive migrations in the intervening period but, if they did, 72% returned to their point of release, or within two miles of it, by the following summer. If more small fish had retained their tags over the winter this percentage would probably be higher, since the year $n + 1$ recaptures are predominantly large fish which are inclined to range more widely.

TABLE VIII. Distances travelled by tagged bass of various length-groups from point of release in year n to point of recapture in year $n + 1$.

Length-group (inches)	Distance (miles)				Total recaptures
	0-0.5	0.5-2.0	2.0-5.0	over 5	
7.0-9.9	3	..	..	..	3
10.0-12.9	3	2	1	..	6
over 13.0	20	15	11	5	51
All length-groups	26 (43%)	17 (29%)	12 (20%)	5 (8%)	60

RECAPTURES BY ANGLING

It is quite certain that few South Bay bass migrate outside South Bay, as the creel census conducted on the neighbouring waters of Lake Huron has not disclosed a single marked bass in six years. However, the recovery of marked fish by anglers in South Bay has not been very useful in determining migrations within the bay. The greater number of creel census returns merely record South Bay as point of recapture. This is in part due to the lack of familiarity with South Bay of some of the anglers, and also to the fact that fishing parties usually fish at four or five different locations in the bay in one day and cannot remember at which one a tagged fish was caught. Some anglers did turn in reasonably accurate accounts of the recapture of tagged fish and these have been analysed.

In all years except 1952 almost all marked fish recaptured by anglers were taken in the vicinity in which they were released. In 1952 when tagging took place in June, instead of July and August as in previous years, the anglers' returns indicate a migration of 12% of the tagged population from the northeast half of the Inner Basin to Jocko Bay. This migration, which suggests greater movement in the month of June, will be considered further in the section dealing with the population.

LOCAL MOVEMENT OF BASS

On one occasion an extensive local movement of bass was observed. This occurred at Trudeau Point (see Fig. 1) in the period August 15–29, 1950. Table IX lists the catches of a trap net which was set in two fathoms off Trudeau Point on August 11, 1950. The average catch after August 17 is more than double the average catch previous to and including August 17. Also the number of tagged immigrants taken after August 17 was more than double the number taken before that date. These two facts—increased catch and increased number of immigrants—indicate a movement of bass into that area.

This is further substantiated by Table X which compares the length distributions of the 1950 catch at Trudeau Point with the distributions of the two previous seasons. It shows a rapid swing from a high percentage of small fish in 1948 and 1949 to a predominance of larger bass in 1950. This was a much different situation from what was expected. In 1949 Trudeau Point was remarkable for small bass, the average length of its catch (9.3 inches) being 1.5 inches smaller than that of any other net. In 1950, with the strong entry of the 1947 year-class into the net fishery, the average length was expected to decrease. Instead the average length increased to 12.7 inches, a rise of 3.4 inches. An influx of larger bass from deeper water would account for this steep increase in average length.

In Table IX the temperatures taken at each lift of the Trudeau Point net are recorded. It is noted that a rapid drop in temperature from 70° to 62°F. coincides with the increased catches and increased immigrants. An east-northeast wind starting before noon on August 15 and continuing for 30 hours was responsible for this change. The actual velocity of this wind is not known, as the anemometer in use at this time could only record up to 15 m.p.h. and the wind exceeded its capacity. Since the longitudinal axis of South Bay runs east-north-

TABLE IX. Trudeau Point trap-net catches in 1950.

Date	Number of bass captured	Number of tagged immigrants	Temperature ° F.
Aug.			
12	6	0	67
15	19	1	68
17	28	4	70
18	48	3	62
22	44	5	63
29	39	8	62

TABLE X. Length distribution, in percentages, of bass captured by the Trudeau Point trap net in the years 1948-1950.

Length-group	Year of capture		
	1948	1949	1950
<i>inches</i>			
7.0- 7.9	3	23	0
8.0- 8.9	15	31	0
9.0- 9.9	24	14	6
10.0-10.9	16	10	19
11.0-11.9	21	11	6
12.0-12.9	12	4	16
13.0-13.9	9	4	18
14.0-14.9	..	2	16
15.0-15.9	..	1	15
16.0-16.9	..	..	4
Average length	10.4	9.3	12.7
Number of fish	68	80	172
Catch per lift	7	8	24

east this wind had therefore the full sweep of the bay. This wind was of sufficient strength and duration to drive the warm surface water to the Narrows and the mouth of South Bay. This piling up of the warm water resulted in a movement of a deeper and colder water mass toward the Trudeau Point region.

A bathythermograph reading taken in South Bay (see location Bt in Figure 1) on August 11 before the storm is presented in Figure 4. This reading shows the epilimnion uniform at 67°F. down to a depth of 35 feet and the thermocline beginning at approximately 45 feet. The 62° isotherm was located at a depth of 52 feet at that time. For the water of this temperature (62°) to reach the Trudeau Point net it would have to move northeast approximately four miles and rise 40 feet. This cold water mass reached Trudeau Point as the rapid drop in temperature indicates.

Corresponding with this water movement was a movement of large bass from deeper water toward Trudeau Point. Of the 21 immigrants taken, 11 had been released from Net No. 51, situated two miles southwest of Trudeau Point. This net was set in deeper water (5 fathoms) and being downwind of Trudeau Point would be in contact with the cold water sooner than Trudeau Point. On August 18 the temperature of the water at this net was 60° compared to 69° on August 16 and the catch was only 2 bass in contrast to an average of 10 bass per lift for this net.

The decrease in catch at Net No. 51, the increased catch at Trudeau Point, the increase in immigrants and the preponderance of large bass combined with the temperature records indicate that a cold water mass moved toward Trudeau Point and in so doing initiated a movement of bass toward this area. Whether the cold water mass drove the bass in front of it or carried them along in the flow is not known.

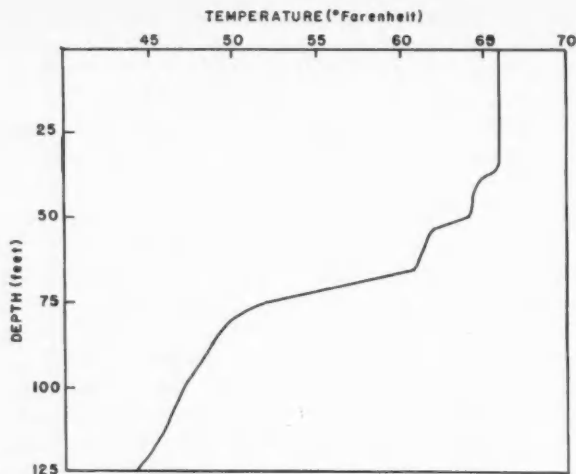


FIGURE 4. Bathythermograph reading taken in South Bay on August 11, 1950.

SUMMARY

Netting and creel census data indicate that approximately 90% of the South Bay bass population is concentrated northeast of a line running from the "Church" to Cornell Point (see Fig. 1). The remaining percentage is scattered throughout the Narrows and Jocko Bay region. The "Inner Basin population" is not dispersed evenly throughout the area, but occurs in varying concentrations at favoured locations along the perimeter. Such locations as Cornell Point, Golding Point and Trudeau Point appear to have their own local populations. The smaller fish (under 13 inches) remain especially localized, whereas there is a transfer of larger bass between locations, of the order of 25%.

There is little migration from the northeast half of the Inner Basin to other areas in July and August, but data on recaptures in 1952 suggest that such a migration occurs in the latter part of June. This migration, which possibly is connected with spawning, requires further investigation.

Since very few bass carried tags from one season to the next, the data on migration over such a period of time are sketchy. Nevertheless, the available data suggest that the greater proportion of South Bay bass will be found in their respective "neighbourhoods" from one year to the next.

Since the South Bay bass population is being more than moderately exploited, the greater percentage of the population consists of small fish (over the six-year period, 70% of the anglers' catch were fish under 13 inches and in 1951 and 1952 over 90% were under 13 inches in length). These smaller fish remain quite localized during July and August and, although some of the larger fish may range extensively, the general picture of localized groups is little altered.

THE CREEL CENSUS

THE SPORT FISHERY

The South Bay smallmouth bass population was exploited over the period of investigation chiefly by anglers from five small commercial lodges and several private cottages located on South Bay, together with five commercial guide boats which operate in these waters. A creel census has been conducted on South Bay in the years 1947-1952 inclusive, by various members of the staff of the South Bay Laboratory.

At the beginning of each fishing season all lodge owners and guides were interviewed by the census worker. He issued creel census cards and supplied instructions for the correct filling out of these cards. The information sought was the number of each species caught, the location of capture, the number of persons fishing, the number of hours fished and the number of boats used. The creel census worker visited the lodges twice a week, on the average, for the remainder of the fishing season. He collected creel census returns and examined any catches that were available. He also questioned the lodge owner as to whether all fishing had been reported on the cards. Since the lodges located on South Bay are small, the lodge owner could usually give a fairly accurate account of the previous three days' fishing and fill in any omissions on the cards. The commercial guide boats were based close to the laboratory and were contacted each night as they returned from fishing. Many fishermen brought their catches to the laboratory for examination; for this cooperation the fish were gutted and, if requested, placed on ice or in frozen storage.

It is estimated that the creel census conducted in the above manner has covered 90% of the South Bay bass fishery in the years 1947, 1948, 1951 and 1952. The coverage was not as complete in 1949 and 1950 and is estimated at 80%. The statistics in Table XI are based on the above estimates.

The effort expended in catching South Bay bass is presented in units of 100 rod-hours. Owing to the variability of creel census returns, the rod-hour has been used with certain reservations. The greater percentage of returns stated two fishermen fishing from one boat, but some reported as high as eight persons fishing from the same boat. It was noted that, when more than two persons fished from one boat, the catch per rod-hour decreased appreciably. This resulted

TABLE XI. Catch statistics of the smallmouth bass fishery of South Bay in the years 1947-1952

Year	Fishing effort	No. of bass caught	Availability	Av. weight	Weight of fish
	100 rod-hours		<i>fish/100 rod-hours</i>	<i>ounces</i>	<i>pounds</i>
1947	15.3	1,362	89	20.0	1,701
1948	22.2	1,556	70	19.0	1,847
1949	20.1	1,026	51	20.5	1,315
1950	18.3	1,209	66	16.5	1,286
1951	21.1	1,605	76	15.0	1,505
1952	26.3	2,292	87	17.0	2,435

partly from the actual difference in availability of bass to each rod; subsequent inquiry revealed, however, that much of the reported fishing time was not spent by the stated number of persons although all spent the same amount of time on the boat. To compensate for this, only two of the number of reported fishermen were considered to be fishing from one boat, thus making the rod-hour equivalent to 0.5 boat-hours.

Table XI reflects the response of fishermen to a good fishing year. The high availability of 89 bass per 100 rod-hours in 1947 resulted in a substantial increase in fishing intensity in the following year. The lower availability in 1948, 1949 and 1950 is reflected in the moderate fishing pressure exerted in the season following, and the increased availability in 1951 resulted in more fishing pressure being exerted in 1952. The amount of fishing pressure exerted on the bass population also depends to a certain extent on the quality of the lake trout fishing. When the lake trout fishing was good the commercial guide boats diverted much of their efforts to this fishery and as a result lessened the fishing intensity for bass. This was definitely the case in 1949 and 1950 when the lake trout fishing was excellent.

The availability figures indicate a rapid drop in the numbers of bass of legal size from 1947 to 1949. The fishery has returned to its 1947 level over the years 1950 to 1952. The entrance of the strong 1947 year-class was responsible for this increase in availability and at the same time it decreased the average weight of the fish landed.

SEASONAL CHARACTERISTICS OF THE CATCH

The angling season has been divided into five periods: the half-months of July and August and the full month of September. Table XII gives the catches for these periods as reported by anglers. The greater part of the fish (82%) are caught in the period from July 16 to August 31, and the peak is reached in the first two weeks of August when 35% of the catch is taken.

Table XIII presents the catch per unit effort for the same periods as Table XII. No seasonal trend is evident except that the availability is consistently high for the month of September. This is at least partly a consequence of a new age-group entering the fishery as it attains legal length toward the end of the season.

TABLE XII. Number of smallmouth bass reported caught by anglers in South Bay during various periods in the years 1947-1952.

Period	1947	1948	1949	1950	1951	1952	All years	Percentage of catch
July 1-15	52	79	175	40	86	243	675	8
July 16-31	128	341	196	165	458	564	1,852	24
Aug. 1-15	406	414	216	513	538	677	2,764	35
Aug. 16-31	436	350	109	175	255	481	1,806	23
September	203	216	125	75	48	98	765	10
Total	1,225	1,400	821	968	1,385	2,063	7,862	
No. examined	497	634	260	313	341	642	2,687	

The greatest contrast between September and the preceding summer months is for 1950, in which year the strong 1947 year-class entered the fishery late in the season.

AGE COMPOSITION OF THE CATCH

Scale samples of the fishermen's catches were taken whenever available. From these samples, which made up 25% of the estimated catches, the age composition has been determined. Table XIV gives an estimate of the age-groups removed from South Bay in the six-year period. South Bay bass enter the sport fishery to a limited extent at age III. The highest age read was XII and age-groups above VII make up only 6% of the fishery. During the six-year period studied, over 75% of the anglers' catch has consisted of age-IV,-V,-VI bass.

As can be seen from Table XIV, there is considerable variation among the contributions of the various age-groups in the years studied. The contribution of an age-group to the fishery in a particular year is, of course, dependent on the success or failure of a certain year-class. The 1947 year-class has been almost solely responsible for the increase in availability shown in Table XI and has restored the quality of the fishery to its 1947 level. Only the larger members of this year-class could enter the fishery in 1950 at age III, but these made up 34% of the catch in that year in contrast with a mean contribution of 8% for this age-group over a six-year period. In 1951 and 1952 the 1947 year-class practically supported the fishery contributing 71% and 67%, respectively, at ages IV and V. Such heavy removals have probably constituted a heavy drain on this year-class. In 1952, 26% of the anglers' catch came from the 1948 year-class at age IV, and this year-class will probably compete for dominance in the sport fishery in 1953.

The occurrence of dominant-classes in smallmouth bass populations has been noted previously. Tester (1932) found the 1928 year-class of bass in Perch Lake maintained dominance in the third and fourth years of life. Doan (1940) reported dominant year-classes in the bass of Lake St. Clair, Cache Lake, Madawaska River and Lake Opeongo. Stone *et al.* (1951) noted dominant year-classes in the bass of Wilson Bay, Lake Ontario. The dominance of any of these year-classes, however, is much less pronounced than that of the 1947 year-class of bass in South Bay.

Doan (1936), noting the dominance of the 1931 and 1933 year-classes in both Lake Opeongo and Cache Lake, suggested that a climatic factor was in-

TABLE XIII. Number of smallmouth bass caught per 100 rod-hours in South Bay in the years 1947-1952 (by periods).

Period	1947	1948	1949	1950	1951	1952	Mean
July 1-15	60	68	52	56	46	119	67
July 16-31	79	71	49	55	93	93	73
Aug. 1-15	89	63	49	62	82	71	69
Aug. 16-31	96	76	44	69	55	88	73
September	94	73	65	139	80	144	99
Year	89	70	51	66	76	87	73

TABLE XIV. The estimated number of smallmouth bass of various ages landed in South Bay in the years 1947-1952. (The values along the diagonal line represent the contributions of the 1939 year-class at ages VIII to XI.)

Year of capture	Age-group									
	III	IV	V	VI	VII	VIII	IX	X	XI	XII
1947	5	218	436	463	136	82	27			
1948	31	218	498	451	264	62	16	16		
1949	205	82	185	267	164	103	10	10		5
1950	411	315	133	169	121	48	12		3	
1951	80	1,140	193	64	32	16	16			
1952	7	589	1,532	78	15	26	26	11	4	4
Mean	123	427	496	249	127	59	18	9	1	1
Percentage	8.1	28.3	32.8	16.5	8.4	3.9	1.2	0.6	0.1	0.1

volved. This might well be true of the 1947 year-class in South Bay, and other waters in the general area. Age determinations of bass from these waters are not available, but the length distributions of anglers' catches in 1950 and 1951 from neighbouring Lake Manitou are recorded in Table XV. The length distributions of South Bay bass are entered for comparison. The predominance of small bass entering the sport fishery in Lake Manitou in 1950 and 1951 indicates the presence of a large 1947 year-class similar to that in South Bay.

THE VIRTUAL POPULATION

Fry (1949) has termed the complete contribution of a year-class to the fishery as the virtual population of that year-class. The virtual population can be estimated if the total catch and the age composition are known for a number of years. Since South Bay bass may reach at least age XII, it would be necessary to conduct a creel census for nine years to determine the total contribution of one year-class to the fishery. There are data for only six years, but as over 90% of the fishery is composed of fish from ages III to VII, the contribution of several year-classes should not be far off the true figure.

The virtual populations in Table XVI are derived from the data in Table XIV. For example, the 1939 year-class (see diagonal line in Table XIV) contributed 82 fish at age VIII in 1947, 16 at age IX in 1948, 10 at age X in 1949 and 3 at age XI in 1950, or a total of 111 fish. Its virtual population at the beginning of age VIII was therefore 111 fish; it contributed 82 fish at that age and the virtual population at age IX was 29, and similarly 13 at age X and three at age XI. The virtual populations of the other year-classes have been calculated in a similar manner and are entered in Table XVI. The bracketed values are means for their columns and have been used to "strengthen" the year-classes 1941-1947. (For example, on the basis of the contributions of the previous year-classes, the 1945 year-class is estimated to contribute 88 more fish to the fishery.)

The virtual population present in any given year can be estimated by adding

TABLE XV. Length distribution of smallmouth bass taken by anglers from South Bay and Lake Manitou in 1950 and 1951.

Length-group <i>inches</i>	1950		1951	
	South Bay	Lake Manitou	South Bay	Lake Manitou
under 10	57	9	53	30
10.0-10.9	84	22	149	75
11.0-	45	6	68	50
12.0-	51	1	36	15
13.0-	29	1	14	4
14.0-	25	4	15	0
15.0-	8	1	10	1
16.0-	3	0	2	0
17.0-	1	2	2	1
Total	303	46	349	176

together the virtual populations of all the year-classes present in the fishery at that time. For example, the virtual population in 1947 can be estimated by adding the values in the top diagonal column in Table XVI (excluding age-III because these fish were mostly not available to the sport fishery). The virtual population in 1947, therefore, consisted of 1,174 age-IV bass, 1,129 age-V, 864 age-VI, etc., or a total of 3,538 fish.

The virtual population is useful in two ways: (1) It can be used (as below) to understand and compare the contributions of various year-classes to the fishery. (2) It can give minimum estimates of a population present in a given year. These estimates, when combined with marking experiments, are useful in making population estimates as is explained later.

TABLE XVI. The virtual population of smallmouth bass of various year-classes at different ages. (This table is derived from the data in Table XIV as explained in the text. The horizontal line in this table corresponds to the diagonal line in Table XIV.)

Year-class	Age-group									
	III	IV	V	VI	VII	VIII	IX	X	XI	XII
1937								5	5	5
1938							43	16	0	0
1939						111	29	13	3	0
1940					212	76	14	4	4	4
1941				864	401	137	34	26	6	(2)
1942			1,129	693	242	78	30	13	(3)	
1943		1,174	956	458	191	70	28	(12)		
1944	698	693	475	290	121	57	(31)			
1945	413	382	300	167	103	(88)				
1946	1,002	797	482	289	(211)					
1947	3,543	3,132	1,992	(460)						

On the basis of the six-year period studied, the South Bay bass fishery requires between 1,500 and 2,000 fish per year (see Table XI). With the average effort that has been expended, a yearly catch of this number of fish would constitute "good fishing". To supply this demand by the sport fishery an average year-class must contribute a minimum of 1,500 bass. When the contributions of various year-classes are studied, the reason for the poor fishing in 1948, 1949 and 1950 is obvious.

The 1942 and 1943 year-classes appear to have been of moderate strength, contributing approximately the minimum of 1,500 fish to the fishery. However, the three year-classes following (1944, 1945, 1946) contributed on the average only 700 fish each, the lowest estimated contribution being 413 fish from the 1945 year-class. In contrast to these poor year-classes, the 1947 year-class, exposed to the fishery only three years, has already contributed 3,083 of its members, and it is estimated it will contribute 400-500 more in future years. This year-class has been almost solely responsible for the recovery of the fishery to its 1947 level. It has, no doubt, depleted itself considerably in so doing, and the fishery requires immediate bolstering by the following year-classes if it is to remain at its present level.

RATE OF EXPLOITATION

As Fry (1949) points out, maximum estimates for the level of exploitation can be calculated, since we know the minimum values for the number of fish at each age present at the beginning of a fishing season. These estimates have been determined for each value in Table XVI (excluding those of the 1947 year-class) up to age IX by calculating the percentage of the virtual population removed in each fishing year. For example, there were 1,129 fish in the 1942 year-class at the beginning of age V. At age VI there were 693, 436 having been removed in the previous season. These 436 represent a removal of 39% from the 1942 year-class at age V. The estimates made in the above manner were then averaged by age-groups to give a mean value for the maximum level of exploitation. These mean values are plotted in Figure 5.

The most reliable data are for the higher ages, as the virtual populations on which these values are based are complete at this level. Figure 5 shows the highest exploitation to be at ages VI, VII and VIII, when 60% of the virtual population at these ages is removed in one season. The lowest exploitation (10%) is at age III, when only a small percentage of bass of this age are over the 10-inch legal limit and thus eligible for the fishery. The exploitation rises steadily from age III to a peak at ages VII and VIII and then falls off at the next higher age. It appears from Figure 5 that, as South Bay bass grow older, they become more vulnerable to hook and line. South Bay bass are caught mainly by still-fishing with worms, minnows or frogs. The writer has noted on several occasions that the bait is first inspected by smaller bass, but that when a larger bass comes into view the smaller ones scatter leaving the bait to the larger fish. Possibly this explains the greater vulnerability of the larger bass.

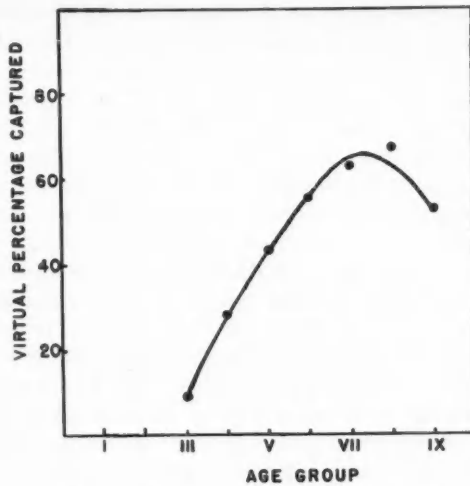


FIGURE 5. The percentage of the virtual population captured at different ages over the period 1947-1952.

AVAILABILITY AND THE VIRTUAL POPULATION

The general availability of bass in South Bay has been calculated for the various years (see Table XI) and has shown definite changes in the size of the bass population exposed to the sport fishery. To see how these changes have come about the availabilities of bass at different ages have been calculated and are entered in Table XVII. For example, 15.3 units of effort were required to catch 463 fish of age V in 1947. The resulting availability was 28.5 fish per 100 rod-hours.

Age-groups III to VI exhibit the largest numbers of fish available to the sport fishery. There are marked fluctuations in the population that any of these age-groups may offer to the fishery from year to year. These fluctuations are due to

TABLE XVII. The number of smallmouth bass of different ages caught per 100 rod-hours in the years 1947-1952.

Year of capture	Age-group										All ages
	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
1947	0.3	14.2	28.5	30.3	8.8	5.3	1.9	...	...	...	89.3
1948	1.4	9.8	22.4	20.3	11.9	2.8	0.7	0.7	...	...	70.3
1949	10.2	4.1	9.2	13.3	8.1	5.1	0.5	0.5	...	0.2	51.2
1950	22.5	17.0	7.2	9.2	6.6	2.6	0.6	...	0.1	...	65.8
1951	3.8	54.0	9.1	3.0	3.0	1.5	0.7	0.8	...	...	75.9
1952	0.3	22.4	58.3	3.0	0.6	1.0	1.0	0.4	0.2	0.2	87.4

the varying degrees of success of the year-classes entering the fishery. The greatest contrast between year-classes is between the 1945 year-class entering the fishery in 1948 at age III and the 1947 year-class entering in 1950 at that age (Table XVII). The availability of the 1945 year-class at age III was 1.4 fish per 100 rod-hours, at age IV it was 4.1, and at age V, 7.2; while the availability of the 1947 year-class at corresponding ages was 22.5, 54.0 and 58.3, respectively. The average availability of the 1945 year-class in its first three years in the fishery was 4 bass per 100 rod-hours, compared to 44 per 100 rod-hours from the 1947 year-class in its first three years. The virtual population of the 1947 year-class on entering the fishery was 3,500 fish in contrast to 400 for the 1945 year-class (Table XVI). This ratio (3,500/400) is close enough to the availability ratio (44/4) to suggest a relationship between availability and the virtual population.

The virtual populations have been sufficiently established from the age compositions of the anglers' catch in the years 1947-1952 to determine if a relationship exists between availability and the virtual populations at various ages (Fig. 6). There are enough data to suggest a good correlation between the availability and the virtual population in age-groups IV to VII, which are the mainstay of the fishery. It is presumed that this correlation holds for the other age-groups but the data are not available as yet.

SIZE COMPOSITION OF THE ANGLERS' CATCH

The length distributions of the various age-groups landed in South Bay in the years 1947-1952 are given in Table XVIII. There are a considerable number of fish in the 9-inch group, which is below the legal 10-inch limit, but the greater percentage of these were just under the limit and fishermen were inclined to stretch both length and imagination. This was particularly the case in 1950 and 1951 with a large year-class entering the fishery and a low availability of the older age-groups.

TABLE XVIII. Length distribution of the various age-groups of smallmouth bass caught by anglers in South Bay, in the years 1947-1952. (Each length-class contains fish from $n.0$ to $n.9$ inches.)

[illegible]

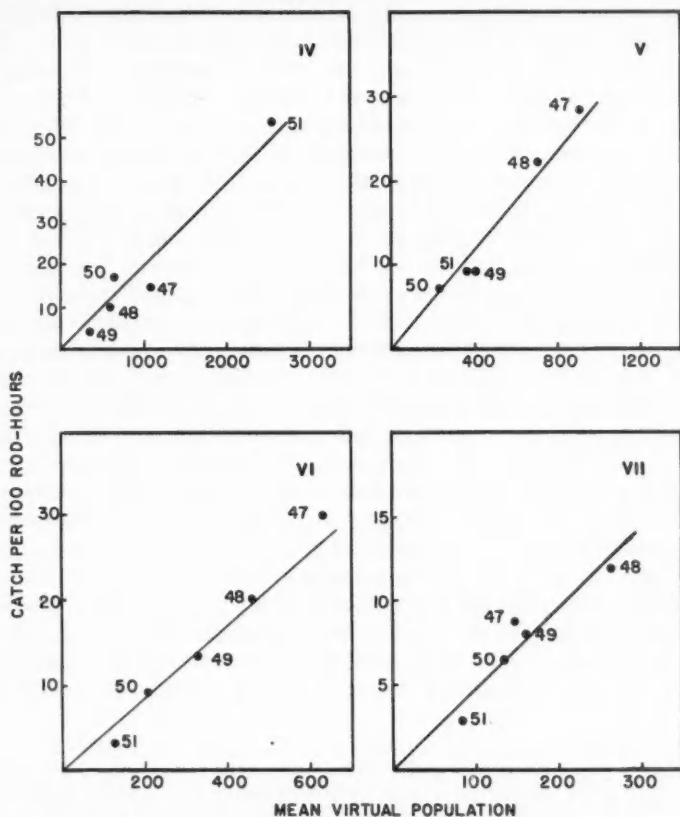


FIGURE 6. The relationship between availability and the size of the virtual population at various ages.

Large smallmouth bass were rarely taken in South Bay; only 5% of the catch were over 15 inches in length and only one bass over 18 inches was reported in the six year creel census. Bass under 12 inches in length made up 58% of the anglers' catch. The average bass taken by anglers over the six-year period has weighed a little over one pound, which weight it usually attains at age V.

The size of the fish landed from year to year is dependent on the relative strength of the year-classes in the fishery. In the years 1947-1949 the average weight of bass landed was 20 ounces (see Table XI). These were mainly fish from the 1941, 1942 and 1943 year-classes. The failure of the 1944, 1945 and 1946 year-classes made it necessary for the 1947 year-class to bear the brunt of the fishery immediately upon entering it, and thus reduced the average weight of the individual bass to about 16 ounces. If this year-class has not been too severely drained, an increase in the average weight of the 1953 catch can be expected.

THE POPULATION

INTRODUCTION

The bass-tagging program carried out in South Bay in the years 1947-1951 has fulfilled but few of the requirements necessary for a valid estimation of the vulnerable population (over the 10-inch legal limit and available to the angler) by either the Schnabel or the Petersen methods. The possibility of estimates of these types is complicated if not nullified by the following three factors: (1) Tagging took place in July and August at the time the sport fishery was in progress thereby ruling out the assumption of a constant population or a constant ratio of marked to unmarked fish. (2) Many fish lost their tags shortly after they were released. Although in certain years the fish were clipped as well as tagged, the clipped fin was rarely recognized by anglers and consequently only the fish examined by the creel census worker could be used in the population estimates. Since only one-quarter of the anglers' catches were examined the figures for recaptures were considerably weakened. (3) The location of bass along the water periphery in varying concentrations and the lack of interchange among these concentrations disallowed the assumption of random mixing.

Situations (1) and (2) above can be rectified in the future by tagging before the angling season begins and using a more efficient tagging method. Situation (3) is not necessarily prohibitive to a population estimate because "random mixing of marked fish among the population is not necessary if the distribution of fishing effort is proportional to the number of fish present in the different parts of the body of water" (Ricker, 1948). This would allow estimates based on recaptures by angling, because angling effort is presumably approximately proportional to the population it is exploiting.

POPULATION ESTIMATE-1952

In 1952 tagging was carried out with the prospect of a reliable Petersen-type estimate of the vulnerable population in the northeast half of the Inner Basin. Since netting and creel census data indicate that the greater percentage of the South Bay bass population is located in this area and since it receives 90% of the angling effort, it was decided to concentrate the tagging at four locations that had shown heavy concentrations of bass in previous years and which were also favourite fishing locations of guides and anglers. At these locations 429 bass were tagged, of which 400 were vulnerable to the sport fishery (over 10 inches). Tagging took place in the last three weeks of June just prior to the opening of the bass fishery on July 1. The tag was a celluloid disc attached to the preopercular bone (see Fig. 2). All bass had their left pelvic fin clipped as well as being tagged.

In the months following tagging anglers reported taking 2,063 bass, of which 642 were examined by the creel census worker. Of these 642 examined fish 45 were previously marked, 11 bearing tags and 34 with left pelvic clips (their tags having been torn off). Using the formula:

$$\text{Population} = \frac{\text{Marked fish extant} \times \text{Number examined}}{\text{Number of marked fish examined}}$$

a population of 5,700 bass was estimated to be vulnerable to the sport fishery. Using DeLury's (1951) formula 1.13, the 95% confidence limits were estimated to be approximately 8,000 and 4,500.

The estimate above was intended for only the population of bass in the northeast half of the Inner Basin, since all tagging was carried out in that area. However 10 of the 45 marked fish recaptured by anglers were caught in the Jocko Bay area, 10 miles distant. At first it appeared that nearly one-quarter of the tagged population migrated to Jocko Bay shortly after tagging. However, of the 2,063 bass reported caught by anglers, 231 (11%) were taken in Jocko Bay and the immediate vicinity. Of the 642 fish examined by the creel census worker, 141 (22%) were from Jocko Bay. The proportion of the Jocko Bay fish in the sample examined is thus twice the ratio of the Jocko Bay catch to the overall catch, it must be halved. Only 71 fish (11%) should have been examined and only catch, it must be halved. Only 71 fish (11%) should have been examined and only five marked fish would have been noted. When this difference in proportion of the sample to the catch is taken into consideration the percentage of fish that migrated is reduced to 12.5%.

The ratio of marked fish to unmarked fish in the sample (35/501 for the Inner Basin and 10/141 for Jocko Bay) is similar for both areas. The local population in Jocko Bay must have been very sparse or it would have altered the ratio in favour of the unmarked fish. Another possibility is that these 10 marked fish recaptured in Jocko Bay were originally Jocko Bay residents which had migrated to the Inner Basin to spawn, were tagged while there, and afterward returned to Jocko Bay. In either case the population estimate of 5,700 legal-sized fish in 1952 includes Jocko Bay residents as well as those of the Inner Basin.

FISHING MORTALITY

Although bass tagging in the years 1947-1951 has not yielded a direct population estimate it has provided an index of fishing mortality. The estimated recoveries, in subsequent years, of fish marked in the years 1947, 1948 and 1949 are entered in Table XIX. These fish were both tagged and clipped, and owing to the heavy loss of tags the data for recaptures are based mainly on clipped fish. Only approximately 25% of the estimated recaptures in Table XIX were actually seen, since only 25% of the anglers' catches were examined. It was presumed that the ratio of marked to unmarked fish in the catches not examined was similar and that the values presented approximate the removal of marked fish by the sport fishery.

Table XIX shows that between 50% and 65% of the fish marked in the years 1947-1949 were recaptured by anglers in the four to five years subsequent to marking. If the tagged population is representative of the population exposed to the fishery, then, out of every 100 bass present in any of these years, approximately 60 were destined to be caught by hook and line within the next four or five years.

The fish tagged in 1947 and 1948 were all of angling size and both suffered the same exploitation, with approximately 50% of the total recaptures being taken

TABLE XIX. Estimated recaptures of bass marked in South Bay in the years 1947-1949, and percentages of the total recaptures from each marking.

Year recaptured	Year and number released					
	1947 (352)		1948 (543)		1949 (1183)	
	Recaptures		Recaptures		Recaptures	
	<i>Number</i>	<i>%</i>	<i>Number</i>	<i>%</i>	<i>Number</i>	<i>%</i>
1947	97	51	...	...	...	...
1948	28	15	190	54	...	...
1949	45	24	56	16	164	27
1950	14	8	60	17	248	40
1951	0	0	23	6	134	22
1952	5	3	24	7	71	11
Total	189	100	353	100	617	100
Percentage recaptured	54%		65%		52%	

in the same season as tagging and 15-25% each in the two seasons following. In 1949 the tagged population was not representative of the vulnerable population, since 25% of the tagged fish were smaller than the legal length of 10 inches. This did not alter the overall fishing mortality too greatly since these smaller fish entered the fishery in the following season. However, the heaviest drain to the 1949 population took place in the year following tagging (40% of the total fishing deaths) instead of the same year as tagging when 27% was taken.

The data in Table XIX demonstrate that, if a number of bass are tagged in South Bay, approximately 60% will be taken by anglers within a period of four to five years, the remaining 40% presumably dying from natural causes. It is assumed that the total vulnerable population (available to the sport fishery) of bass in South Bay suffers a similar exploitation.

POPULATION ESTIMATES BASED ON FISHING MORTALITY

Since marking has shown that approximately 60% of the bass reaching legal size are taken by angling in subsequent years and since the number of fish taken by angling is the statistic designated the virtual population, then the virtual population in any year can be taken to represent approximately 60% of the vulnerable population (e.g. population available to the sport fishery).

As was explained on page 165 each diagonal column in Table XVI represents the virtual population present in a certain year. The top diagonal column represents the year 1947 and by summing the values in this column (excluding age-group III) the virtual population in 1947 is found to be 3,538 fish.

Since 3,538 represents the number of fish removed by angling from the population present in 1947 and tagging data indicate a subsequent 60% reduction of that population by the sport fishery, then these 3,538 fish represent 60% of the

1947 population. The vulnerable population in 1947 was therefore $3,538 \times 100/60 = 5,900$ bass.

In a similar manner estimates of the virtual population and, in turn, the vulnerable population have been made for the years 1948, 1949 and 1950 and are entered in Table XX. The vulnerable population has decreased from a high of 5,900 in 1947 to a low of 2,900 in 1949. The 1950 estimate is low owing to a peculiar situation arising from the entrance of the dominant 1947 year-class into the fishery. In other year-classes the number of fish attaining legal length at age III was negligible, and thus, in the estimates age-III bass were not considered vulnerable. However, the 1947 year-class, having considerable strength in numbers, contributed 411 of its members at age III (34% of the 1950 catch). This was due to the very low availability of the previous year-classes (see Table XVII) with the result that the 1947 year-class at age III received more than average fishing intensity; even to the extent that 51% of its contribution in that year was under the legal length when caught.

In Figure 7 the population estimates for the years 1947-1950, as well as the Petersen estimate for 1952 have been plotted against the catch per unit effort in these years. In all years except 1950 (see above) a good correlation exists. The high populations of 5,900 and 5,700 in 1947 and 1952 offered 89 and 87 bass per 100 rod-hours, respectively, to the angler, whereas the low population of 2,900 bass in 1949 provided only 51 bass per 100 rod-hours.

The population estimates plotted in Figure 7 are only as accurate as the data will allow, but in conjunction with the catch data and the catch per unit effort they present a reasonable description of the population trend. The assumption that the catch per unit effort reflects the size of the population appears to hold true in the case of South Bay smallmouth bass.

THE SPAWNING POPULATION

Estimates of the spawning population, similar to those of the vulnerable population, have been made for the years 1947-1950 (Table XX). These are based on the assumption that 75% of the age-V females and all older females are capable of spawning (p. 155, above). Since the sex ratio is even and the males mature earlier than the females, there should be no scarcity of male breeders.

The estimates indicate that the spawning population has decreased steadily from 3,500 fish in 1947 to 1,400 in 1950. A study of the virtual populations in

TABLE XX. Estimated populations of smallmouth bass present in South Bay in the years 1947-1950. (For explanation see text.)

Year	Virtual population (age IV & older)	Vulnerable population (legal size)	Virtual spawning population	Estimated spawning population
1947	3,538	5,900	2,082	3,500
1948	2,869	4,800	1,938	3,200
1949	1,726	2,900	1,232	2,000
1950	1,697	2,800	843	1,400

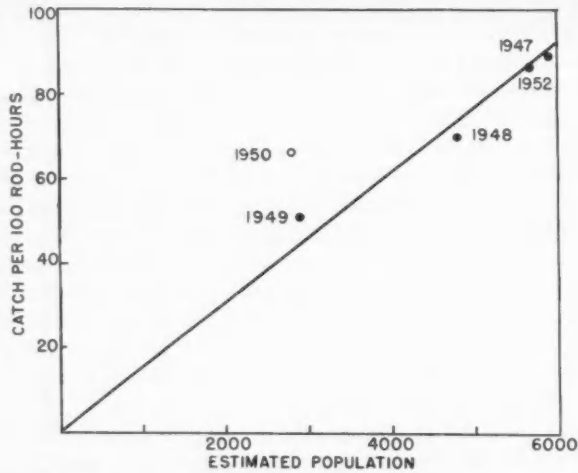


FIGURE 7. The relationship between the catch per unit effort and the estimated population.

Table XVI suggests a further decrease in 1951, but the dominant 1947 year-class reached spawning age in 1952 and the number of spawners should have increased substantially in that year. It is difficult to estimate what effect the decrease in spawning stock will have on the fishery in future years, but continuation of the South Bay creel census will reveal whether a correlation exists between the number of spawners and the strength of the resulting year-class.

DISCUSSION AND CONCLUSION

The size of the South Bay smallmouth bass population has undergone considerable changes in the years 1947-1952. The collected data indicate that the legal-sized population (vulnerable to the sport fishery) was at a high in 1947 and decreased steadily until it was approximately half that size in 1949. Since 1950 the population has increased again to its 1947 level. Population estimates place the numerical strength at 5,900 fish in 1947, 2,900 in 1949 and 5,700 in 1952. These estimates agree reasonably well with the catch and catch-per-unit-effort data collected in the creel census.

This bass population is at present exposed to a sport fishery which is probably more intense than is beneficial to its future status. Since the catch of large bass in South Bay is very small, a larger catch of small fish is more or less demanded. The present fishing pressure requires a yearly catch of 2,000 bass if fishing success is to remain at its present level, which is considered "good". A certain amount of fishing pressure is due to the poor state of the South Bay lake trout fishery at the present time (Fry, 1952). The guides, especially, have diverted their efforts from the lake trout to the catching of bass. An attempt is being made to re-establish the lake trout population by plantings of yearling lake trout and, if this is successful, the pressure on the bass population will be lessened.

To sustain the bass fishery at 2,000 fish per year each year-class must on the average contribute this number to the fishery. Over the past six years certain year-classes have failed to make such a contribution. The 1944, 1945 and 1946 year-classes have not contributed even half the required number of fish, with a resulting decrease in the quality of the fishing in 1948, 1949 and 1950. The fishery was restored to its present production only by the outstanding contribution of 3,500 members of the 1947 year-class.

The problem of sustaining the fishery at its present level is apparently one of recruitment. Recruitment, in turn, raises the problem of available spawning stock. There are no data to indicate the number of spawners from which the 1944, 1945 and 1946 year-classes arose, but we have estimates of the spawning population in the years 1947-1950. The population capable of spawning in 1947 is estimated to have been 3,500 fish. This spawning stock contributed an estimated 3,500 fish to the sport fishery in subsequent years. The spawning stock has decreased steadily since 1947 to a low of 1,400 in 1950, and probably decreased further in 1951. In studying such a decrease the question arises as to how low a spawning stock may be allowed to rest before it adversely affects the sport fishery.

Temperature, wave action, fungus infection, capture of guardian male bass, predation, etc., have all been cited as factors reducing recruitment. Undoubtedly many or all of these factors are at work in South Bay and all take their toll in varying amounts from year to year depending on their disposition. However, in the past 12 years none of these, nor all combined, have completely obliterated a year-class. Is it possible then, that within limits, if the spawning escapement were increased, the contribution of that year-class to the fishery would be increased?

Evidently smallmouth bass suffer their greatest losses as embryos and newly hatched young. Reighard (1905) found that 44% of the nests under observation in a hatchery pond were unsuccessful, but could not attribute this loss directly to the effects of the environment. Doan (1936) noted that 4 out of 11 natural nests under observation were complete failures and that in the remaining nests the number of fry were greatly reduced in their early stages. Webster (1947) observed a high mortality of eggs and young during three spawning seasons in Taughannock Creek. He noted a high incidence of fungus infection in these nests as well as other nests located in Cayuga Lake. From the observations of these and many other investigators we may conclude that the mortality of eggs and newly hatched young is quite high.

Is it this initial high mortality that determines the number of fish reaching the fishery or is it the availability of food and density of predators that await the survivors? If it is a matter of food supply and predation, the number of spawning fish (over a minimum) is not decisive. If, however, it is the mortality that occurs during and immediately after spawning, the amount of spawn laid down assumes greater importance.

To date, bass spawning and various factors affecting it have not been investigated in South Bay. Likewise, little is known of the available food supply and the predator density that awaits surviving fry, but these factors are not believed to be limiting. The problem is presumably one of increasing the number of sur-

vivors. The possible solutions, then, are (a) determining the factor or factors causing the high mortality at spawning time and neutralizing them; (b) restrictions that will ensure a higher spawning population; (c) supplementing the surviving fry by plantings of fingerlings.

The third course has already been undertaken in South Bay to determine its worth. Plantings of 2,437 fingerling bass in 1951 and 2,116 in 1952 have been made in South Bay. These fingerlings were three months old and had attained an average length of two inches. These fish were marked by clipping the right maxillary in 1951 and the left maxillary in 1952, a method apparently used with success by Webster (1949).

Continuation of the South Bay creel census in future years is essential to a more thorough understanding of the dynamics of the smallmouth bass population and the effect of the fishery upon it. In particular, an attempt should be made to examine as large a portion of the anglers' catch as possible in order that the value of planting fingerling bass may be assessed. Also, a thorough study of bass spawning and all factors affecting it is necessary if we are to approach an understanding of the complex problem of recruitment and possible methods of increasing it.

SUMMARY

1. The smallmouth bass population of South Bay and the sport fishery imposed on it have been studied by means of a tagging program and a creel census carried out in the years 1947-1952 inclusive.

2. The collected data indicate that the main concentration of bass is located in the northeast half of the Inner Basin and that 90% of the sport fishery occurs there.

3. In the years 1947-1952, 3,647 smallmouth bass were marked either by tagging or fin-clipping or both. Approximately 80% of the tagged fish lost their tags in the same season as tagging.

4. The growth rate of South Bay bass has been determined by (a) scale readings, and (b) use of yearly length increments of tagged fish. The growth rate compares favourably with that found in other Ontario waters.

5. Migration data indicate that South Bay bass range very little during July and August. Larger bass range farther than small bass.

6. The yearly angling catch ranged from a low of 1,026 bass in 1949 to a high of 2,292 in 1952. The catch per unit effort paralleled this trend with a low of 51 bass per 100 rod-hours in 1949 to a high of 87 in 1952.

7. South Bay bass enter the fishery in small numbers at age III. Seventy per cent of the anglers' catch consisted of bass of ages III to V inclusive.

8. The 1947 year-class dominated the fishery in 1950, 1951 and 1952, contributing 34%, 71% and 67%, respectively, of the anglers' catches in these years.

9. The occurrence of a dominant year-class in neighbouring waters (also) suggests that a climatic factor may have been involved in determining the success of this year-class. On the other hand, the 1947 year-class arose from a very substantial spawning population.

10. The contributions of several year-classes to the fishery (virtual popu-

lations) have been determined and these exhibit considerable variation in numbers.

11. Maximum estimates of the level of exploitation show that older bass are more vulnerable to hook and line than smaller bass. The highest exploitation was 65% at ages VIII and IX.

12. Recaptures of marked fish by anglers indicate that 60% of a population tagged in one year will be taken by angling in the succeeding four or five years.

13. Estimates of the population of legal-sized fish show a decrease from 5,900 fish in 1947 to 2,900 in 1949 with an increase again to 5,700 in 1952. The catch per unit effort data support these estimates.

14. The South Bay bass fishery reflects the variation in recruitment in different years. The recruitment in certain years has not been sufficient to meet the demands of the fishery. (In 1951 and 1952 recruitment was supplemented by plantings of marked fingerling bass.)

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Phototactic and Pigmentary Responses of Sockeye Salmon Smolts following Injury to the Pineal Organ^{1,2}

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ABSTRACT

Light sensitivity of the sockeye salmon smolt (*Oncorhynchus nerka*) is dependent upon the pineal organ as well as the eyes. Destruction of the pineal area of the brain affects the distribution of pigment in the chromatophores and the phototactic response of the fish.

INTRODUCTION

PHOTOSENSITIVITY of the pineal and adjacent areas of the diencephalon has been described in several different fishes. In the cyprinid, *Phoxinus laevis*, photoreceptors in this region are clearly involved in chromatophore responses (von Frisch, 1911) while the marked colour rhythm displayed by *Lampetra* is abolished in the blind ammocete and disturbed in the adult by destruction of the pineal (Young, 1935). Orientation with respect to light may also depend on photoreceptors in the pineal area. In the blind Mexican cave characin, *Anoptichthys*, the sign of the phototaxis is determined by the exposure of the pineal region (Breder and Rasquin, 1947). This response has an obvious survival value for blind *Anoptichthys* that might find themselves near the outlets of caves. Breder and Rasquin (1950) find that, in general, fishes with translucent tissue over the pineal area are light positive, while those in which these tissues are more opaque are light negative. Rivas (1953) has described the elaborate pineal apparatus of the tuna (*Thunnus thynnus*) and postulated an important role for this apparatus in controlling the phototactic movements of tuna.

On the basis of these findings, James W. Atz, New York Zoological Society, suggested in a private communication that the different phototactic responses displayed by juvenile salmon (Hoar, 1954) might depend on the relative exposure of the pineal area. During the spring of 1953 it was possible to test this theory using migrating sockeye salmon smolts of Lakelse lake, British Columbia.

MATERIALS AND METHODS

The field work was carried out at the Lakelse field station of the Fisheries Research Board of Canada. Four galvanized iron washtubs were placed side by side on a platform in the same creek where sockeye smolt were retained for experimental purposes. Water flowing around the tubs maintained the temperature in the tubs at that of the creek. The interior of one-half of each tub was painted

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with aluminum paint and exposed while the other was painted dark red and covered with a tightly fitting plywood cover. The latter extended down vertically across the middle of the tub to about 3 cm. below the surface of the water. Water in the tubs was about 20 cm. deep. It was changed twice daily. Observations were made from behind a screen on the bank of the creek.

Four groups of fish were compared: controls; blinded fish; fish with pineal area probed; and blinded fish with the pineal area probed. Fish were blinded by injecting phemerol chloride (Parke-Davis, 1:1000) into the posterior chamber of the eye. The pineal area was destroyed by probing with a sewing needle. The localization of the region presents little difficulty, since the parts of the brain are clearly visible through the transparent dorsal coverings (Fig. 1). Many of the injuries were later verified by histological examination of sagittal sections. The histological work was carried out by Mrs. K. Newman, working on a grant from the National Research Council of Canada.

RESULTS

GENERAL OBSERVATIONS AND COLOUR RESPONSES

The dorsal covering of the head of a sockeye salmon smolt is quite transparent. When the fish is on a light background, and melanin-clumped in consequence, the major areas of the brain are clearly evident (Fig. 1). Dissection of formalin-preserved specimens reveals a conspicuous round patch of dark pigment above the pineal body. It is, therefore, concluded that the sockeye smolt belongs to that group of fish which can cover or uncover the pineal area by pigmentary response (Breder and Rasquin, 1950).

Four groups of 6 fish each were observed for several days in aluminum-painted tubs exposed to outdoor illumination. This experiment was later repeated. Descriptions of colour given here were made by Otto Fingerhut who was not acquainted with the nature of the experiment or the type of injury involved. The photographs (Fig. 1) were taken by Alan Beach.

Unoperated controls, during daylight hours, were easily startled when the observer approached. Movement in the vicinity of the experiment produced definite avoiding reactions. At night the beam of a flashlight caused the fish to dart wildly around the tub. On this particular background their colour, in daylight, was described as light brown with dark brown spots (Fig. 1A). The blinded fish, on the other hand, showed no avoiding reaction during the day but were readily startled by the flashlight at night. The colour of these blinded fish was dark green-brown with obvious black spots (Fig. 1B). Reaction to the flashlight at night was abolished when both pineal complex and eyes were destroyed. Fish injured in this way showed no avoiding reaction at any time. The colour was coal black or jet black except for the silver ventral surface. No spotting was evident. The darkening of pigmentation is expected in teleosts when the nervous control is removed (Parker, 1948). The appearance of this group was always uniform (Fig. 1C). When the pineal complex alone was destroyed, the fish showed a definite avoiding reaction, similar to that of the controls, both day and night. The

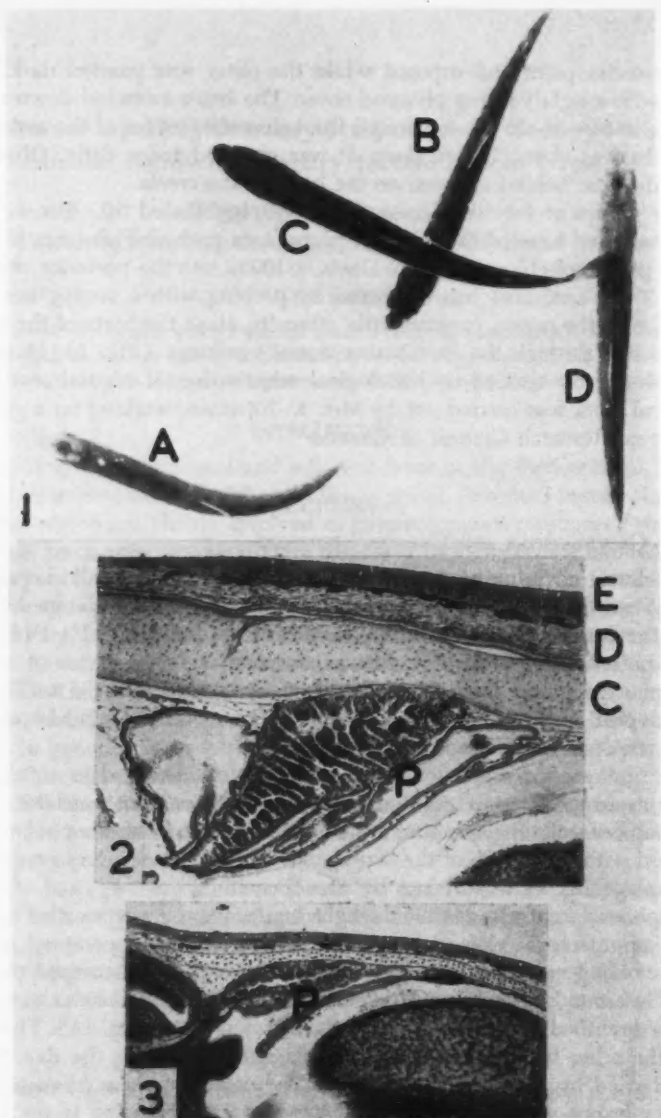


PLATE I

FIGURE 1. Sockeye salmon smolts on white background. A, control; B, blinded; C, blinded with pineal area probed; D, pineal area probed; magnification about 2/3.

FIGURE 2. Mid-sagittal section of pineal region of control sockeye smolt (52 \times). E, epidermis; D, dermis; C, cartilage; P, pineal complex. Note melanophores between epidermis and dermis, also thin layer of bone between dermis and cartilage.

FIGURE 3. Mid-sagittal section of pineal region of control sockeye fry (52 \times). P, pineal complex.

colour response in this group was variable. As a group they were darker than the controls but lighter than the blinded fish (Fig. 1D).

PHOTOTAXIS OF SOCKEYE SMOLT

Data on four different experiments are summarized in Table I. In the first two experiments the four groups of fish described above were compared simultaneously. In the third experiment duplicate groups were blinded or had their pineal region probed. In the fourth experiment the two groups of blinded fish studied in experiment 3 were probed in the pineal area and compared with two groups of unoperated controls. In every case 6 fish were used in each tub. Observations were started on the day following the operation and usually continued for two days. Recordings of the position of fish with respect to the exposed or covered area were made at 1-minute intervals for periods of 9 minutes (10 positions) about every 2 hours throughout the day. Light intensity and temperature were recorded after each set of observations. Oxygen was tested periodically.

TABLE I. Frequency with which sockeye were found in either of two halves of a tub—the exposed or the darkened—when blinded, with pineal destroyed, or both. Figures show the percentage of smolts in the *exposed* half. During each observation period the distribution of 6 fish was recorded at 1-minute intervals, 10 times. An asterisk indicates that the chi-square total did not show significant departure from the average distribution of 3 fish per area at 0.01 probability. "T" indicates territorial behaviour.

Experiment number	Duration	Number of observation periods	Control	Blind	Pineal destroyed	Blind, pineal destroyed
	<i>days</i>		%	%	%	%
1	2	13	9.8T	16.1	29.3	43.8*
2	3	20	15.3T	17.0	43.3*	44.1*
3	2	12	...	7.7	1.2	...
			...	19.5	45.0*T	...
4	1	10	10.8T			44.3*
			27.5T			33.3*

Unoperated control fish are negatively phototactic (Table I). Sockeye smolt emerge from the covered area only at a low light intensity or when members of the group show aggressive behaviour. This territorial behaviour is not infrequently observed in sockeye smolt confined in restricted areas (Hoar, 1954). In the apparatus used in the present experiments a dominant fish, if present, always defended the covered area of the tub and chased other fish into the uncovered area. This complicated the picture in several of the groups with normal vision.

The reaction of blinded sockeye smolt is essentially the same as that of the control fish when measured by percentage distribution (Table I). In this case, the quantitative comparison is somewhat misleading, since blinded fish never show aggressive behaviour while controls occasionally do. In other words, the departure from consistent negative phototaxis is associated with aggressive behaviour in the controls (occasionally low light intensities) but is apparently due

to reduced sensitivity to light in the blinded fish. In any case, negative phototaxis is still marked in blinded fish and in marked contrast to the next group described.

When blinded fish are also subjected to the destruction of the pineal region of the brain, they become almost completely insensitive to light. Distribution in the tubs does not show a significant departure from uniform as measured by the chi-square test (based on chi-square totals for all positions recorded in any experiment, 100–200 degrees of freedom). It is interesting, however, that in each of the four comparisons slightly more than 50% of the fish remained in the dark. Von Frisch (1911) found a somewhat diffuse distribution of photoreceptors in the pineal region of *Phoxinus laevis* L. and a small degree of photosensitivity may have remained in the blinded sockeye salmon smolts with pineal area probed.

The data for salmon with intact eyes but with injured pineal area are less consistent (Table I). In the first place strong territorial behaviour was evident in one group of fish (second group in experiment 3). Moreover, it was difficult to control the injury. In experiment 3 the injury was slight (Fig. 4), while in other cases it was much more extensive (Fig. 5). In some cases the injury was evidently in the forebrain proper while the pineal body itself seemed intact (Fig. 6). The variable response of the chromatophores is also evidence of the variability of the injury. For this reason, groups of fish with pineal destroyed but with intact eyes are not particularly useful in supporting the conclusions. However, the importance of the pineal region in control of phototactic behaviour and response of chromatophores seems adequately demonstrated by comparisons of the other three groups.

PHOTOTAXIS OF SOCKEYE FRY COMPARED WITH SOCKEYE SMOLT

A marked difference in depth preference of sockeye fry and sockeye smolt has been observed (Hoar, 1954). Whether this results from increased activity of the smolt or whether real changes in phototaxis of sockeye fry and/or depth preference occur at this time is not clear. It is of interest, then, to compare the phototaxis of fry with smolt under identical conditions to those used for the experimental fish just described and examine any differences that appear in terms of the pineal functions demonstrated.

In the course of two experiments 4 lots of smolt were compared with 4 lots of fry. The data summarized in Table II suggest that the smolts are more sensitive to light and exhibit a stronger negative phototaxis than the fry. The values for smolt in Table II are of a same order as those for control fish in Table I. Variability is due to aggressive behaviour. On the average 16% of the smolt were found in the lighted half of the tubs during the observations while about twice as many fry appeared.

A strong negative phototaxis had previously been demonstrated in sockeye fry studied in a vertical column of water and in a horizontal light gradient (Hoar, 1954). Therefore, the reaction displayed by sockeye fry in the present experiments was checked with 12 additional groups of sockeye fry. Each group

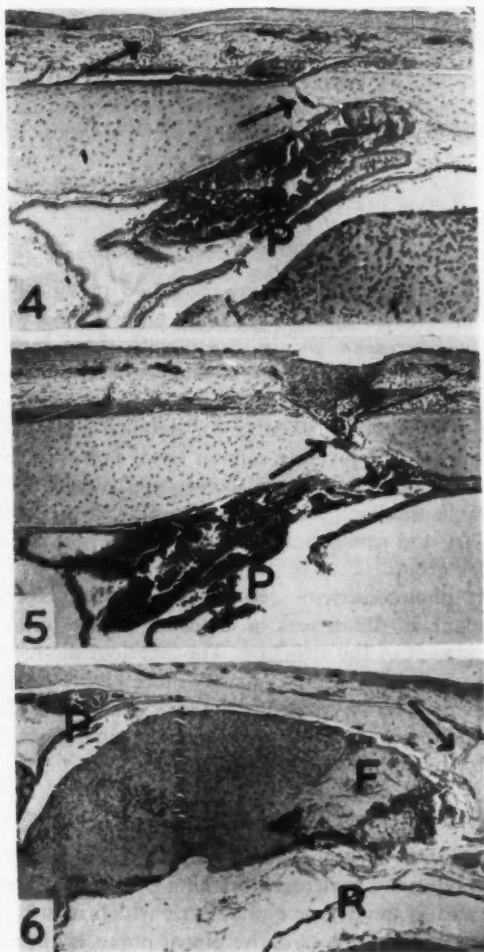


PLATE II

Mid-sagittal sections of pineal region of sockeye smolts to show type of injury involved (52 \times). Arrows indicate points where needle passed through skin and cartilage. P, pineal; F, forebrain; R, remains of retina.

FIGURE 4. Slight injury with some disorganization of pineal.

FIGURE 5. Extensive disorganization of pineal.

FIGURE 6. Injury in forebrain and optic region with shrunken pineal complex.

TABLE II. Comparison of sockeye smolts and fry in the exposed-darkened tub. Figures show the percentage in the *exposed* area. In each case positions were recorded at 1-minute intervals 10 times on 12 different occasions. "T" indicates territorial behaviour.

Smolt	Fry
%	%
3.3	32.0
19.3T	32.0
35.6T	35.4
5.8	28.7

was observed for a period of one day as described previously. The mean percentage of fish in the lighted half during these observations was 33.3 (standard deviation, 6.2). The figures are in agreement with those in Table II. The reaction of the fry seemed to depend on light intensity and particularly on the rate of change in light intensity. Although light intensity was recorded during these experiments, conditions were too variable for detailed analysis. Comparisons of the phototactic behaviour of juvenile salmon have, however, been made under controlled laboratory conditions and will be reported subsequently. The findings are in agreement with those reported here and show a predominantly negative phototaxis in both fry and smolt, but the negative reaction is considerably more marked in the latter group.

Differences in photosensitivity of sockeye fry and sockeye smolt may possibly be dependent on differences in exposure of the pineal area or differences in the development of the structure. The histological study shows that the pineal body of the smolt (Fig. 2) is internally more highly convoluted than that of fry (Fig. 3) and may be physiologically more sensitive to light. A more detailed investigation is required before differences in phototaxis of smolt and fry can be attributed to their pineal physiology.

DISCUSSION

The experiments show clearly that the pineal region of the sockeye salmon smolt is sensitive to light and that receptors here play a part both in the control of chromatophores and in the negative phototaxis which is so marked in juvenile sockeye. The amount of light reaching the pineal organ is apparently controlled by the distribution of pigment in a patch of chromatophores above this area of the brain. Breder and Rasquin (1950) report that fish capable of such control often show what appears to be an erratic behaviour in regard to their reactions to light. The variable responses to light shown by sockeye at different times in their life history and in different experimental situations is perhaps, then, to be expected.

Sockeye fry used in this study had recently hatched from the gravel of a stream and were descending into Lakelse Lake. The smolt, on the other hand, had spent one year or longer in the lake and were descending the outlet river toward the ocean. These migrations occur at low light intensity and the photo-

sensitivity of this area of the brain may in some way be involved in the activities. Differences in degree of negative phototaxis of fry and smolt may be correlated with differences in the degree of pineal development. At the moment, however, there is no evidence for this speculation and it can only be concluded that the pineal region of the brain of the sockeye smolt is photosensitive and plays an active part in chromatophore control and in the negative phototaxis characteristic of the sockeye smolt.

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